VOYAGER SUPPORT STUDY

IMPLEMENTATION DEFINITION

FINAL REPORT

SUMMARY

TRW
SYSTEMS GROUP

04480-6010-R000

VOYAGER SUPPORT STUDY

IMPLEMENTATION DEFINITION

FINAL REPORT

SUMMARY

JULY 1967

Prepared for
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Jet Propulsion Laboratory
Pasadena, California

Under Contract Number 951113

TRW SYSTEMS
ONE SPACE PARK
REDONDO BEACH, CALIFORNIA

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ILLUSTRATIONS

1. INTRODUCTION

The Implementation Definition Task of the TRW Voyager Support Study reported here is a sequel to the previous completed Advanced Mission Definition Study (TRW report 04480-6001-R000, November 1966). The project concept developed in this earlier work has been extended in terms of implementation definition covering developmental and operational activities, schedules, and project costs. This volume summarizes the highlights of the study separately bound from the study report itself, as a convenient means for viewing the major results.

The Mars exploration by the program under study is expected to lead to a significant level of understanding regarding that planet. This premise, when applied to the advanced missions in the last half of the 1970's leads to a comprehensive exploration capability, and in turn has a significant impact on the technical approach for the initial missions. Hence, project definition within this framework revolves around critical questions of when and how, in addition to what exploratory capability should be provided.

The underlying objective of this study has been, therefore, to achieve insight regarding such implementation considerations and an understanding of the means by which the Voyager project can most effectively and economically be pursued. Although studied for the project approach derived in the previous task, many of the implementation considerations discussed are of a general nature and should therefore be applicable to the actual Voyager project. The approach for the study has been to identify and evaluate alternatives so as to arrive at a reference implementation definition. Such a reference is not intended to represent a definitive recommendation, however, but rather to facilitate the investigation and evaluation of the various alternatives within a consistent framework. The evaluation of such alternatives is implicit in the synthesis of the approach presented, but because of its importance to the study, additional discussion has been included in this summary volume.

The underlying motivation for the study, as well as for the preceding advanced mission definition work, has been to generate independent input regarding Voyager program definition. In addition, there will be differences between the study material and current Voyager planning due to changes since the study ground rules were established in April 1966. Thus, many of the assertions about the Voyager program are made in the context of the reference approach and so may not apply to current official plans. Although an effort has been made to stay within basic NASA project implementation policy in laying out the overall project framework, many Voyager-peculiar considerations have been derived and formulated on an independent basis.

In examining the development of the capsule system, substantial use has been made of the work completed in this area by Grumman Aircraft Engineering Corporation. Similarly we have made extensive use of the recent work by the AC Defense Laboratories of the General Motors Corporation on the Voyager mobile unit.

2. PROJECT DEFINITION

The general features of the plan upon which the implementation study is based are as follows:

- Comprehensive Mars exploration on an expeditious basis
- Initial orbiting and landing missions at the 1973 launch opportunity
- Precursor life detection mission as a prerequisite for definition of the ultimate surface laboratory
- A two- or three-step surface laboratory development
- A standard flight spacecraft with payload changes as appropriate, with propellant loading varied from mission to mission
- A standard flight capsule (less science) sized for the advanced mission payload and offloaded for earlier missions as appropriate

2.1 PROJECT EVOLUTION

Since the development lead time for any particular launch opportunity is too long to allow substantial application of results from one launch opportunity to the next, an advance in system development that requires previous mission experience can occur only after skipping one launch opportunity. Thus any major stage of development is applicable to a set of at least two missions, and such a set can be designated as encompassing one mission generation. For the program under consideration covering six launch opportunities, three such generations are possible.

The reference project approach calls for either two or three generation programs, as illustrated in Figure 1, depending on what is discovered on Mars. A simplified precursor landed science payload is utilized in the first-generation 1973 and 1975 missions. If life is detected and cultured, then definition and development of the final surface laboratory can proceed. If life is not detected or cultured on

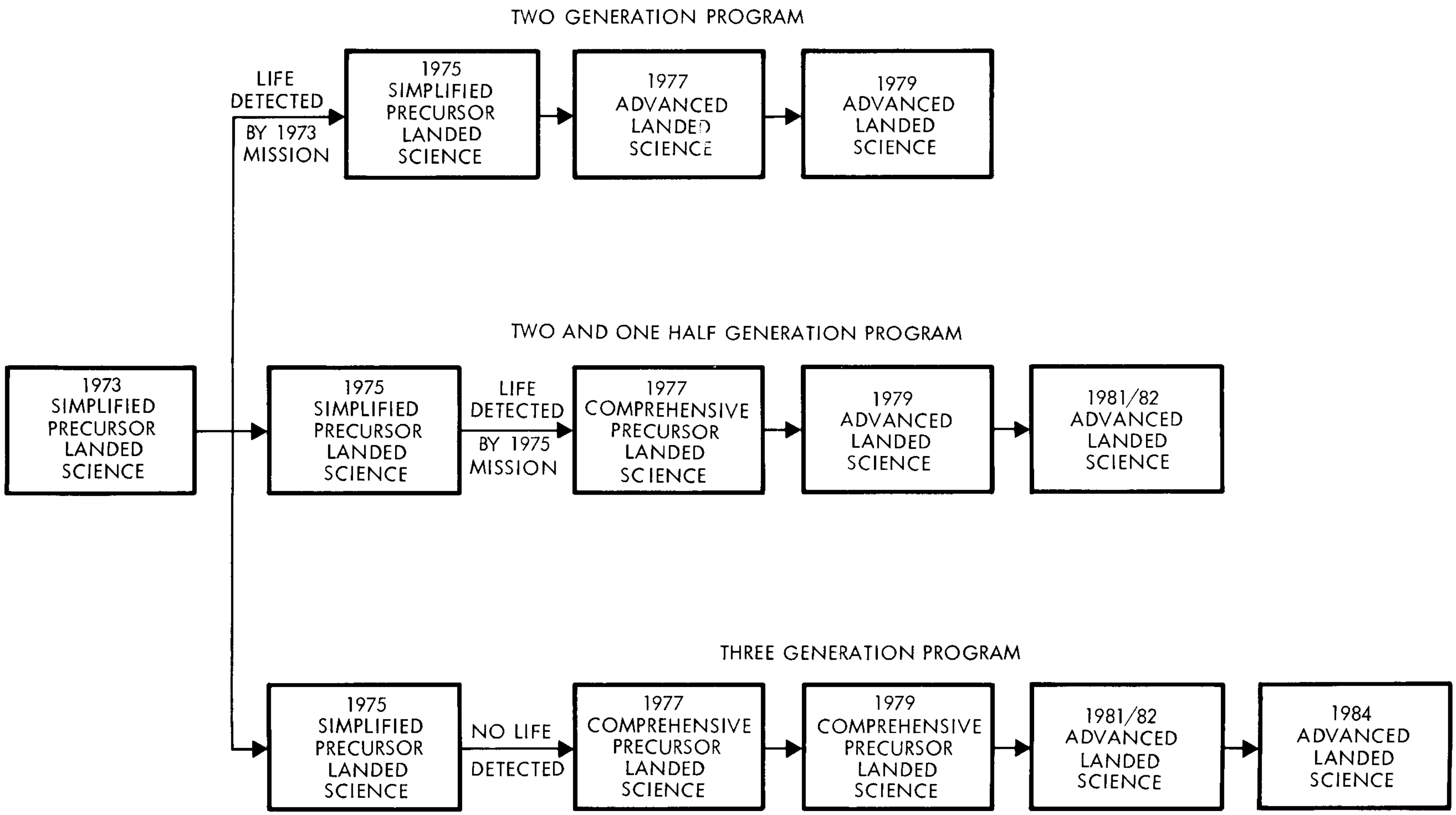


Figure 1. Voyager Program Progression

the first generation, we proceed to a mission generation which lands a comprehensive precursor payload. This incorporates a long-life automated laboratory whose details will be based on data derived during the first generation but which will provide life detection experiments rather than the capability for advanced biological investigations, since if life is not detected there will be insufficient evidence for defining the requisite advanced laboratory characteristics. On the basis of the more thorough findings from this second generation, then, the third generation will incorporate an advanced surface laboratory to permit sophisticated biological investigations utilizing microbiological experimentation or biochemical analysis as appropriate.

The strategy thus calls for a standardized basic capsule, flight spacecraft, landed science support, and an approach to the landed science payloads permitting a three-generation evolution.

2.2 PROJECT ELEMENTS

The first-level work breakdown segments for a NASA project are designated as systems. In keeping with this definition, such systems correspond to the project organizational structure just below the project level. This structure then corresponds to administrative or contractual alignments having direct responsibility for the related work. At the same time each system is related to some principal functional entity for the project. For the reference Voyager project of the current study there are six such systems:

- Launch Vehicle System
- Spacecraft System
- Capsule System
- Launch Operations System
- Mission Operations System
- Tracking and Data Acquisition System

The launch vehicle system includes the Saturn V, the Voyager shroud, and the contractor personnel for the stages of the Saturn V assigned to support the launch operations at KSC.

The spacecraft system includes the spacecraft bus, propulsion, planetary vehicle adapter, and mission-dependent equipment and software for handling spacecraft telemetry and commands at DSN stations. It includes as well the facilities needed at KSC and elsewhere to develop, assemble, and test the spacecraft. Similarly the capsule system covers the capsule flight hardware, associated MDE and OSE, and related facilities.

The launch operations system includes the KSC Complex 39 facilities assigned to Voyager and support from the Air Force Eastern Test Range. The mission operations system incorporates these parts of the SFOF assigned to Voyager, and the tracking and data acquisition system includes these elements of the Deep Space Net and others assigned to support Voyager in tracking and data acquisition.

The major elements of mission flight hardware are defined below.

- Launch Vehicle. The launch vehicle consists of the Saturn S-IC stage, S-II stage, S-IVB stage, instrument unit, interstage equipment, and shroud system. The shroud system is peculiar to Voyager and allows for individual encapsulation and handling of the planetary vehicles.

- Planetary Vehicle. A planetary vehicle consists of one flight capsule and one flight spacecraft mated for launch.

- Flight Capsule. A flight capsule consists of a lander and a canister/adapter. The lander is the element that separates and descends to the Martian surface; it is made up of a capsule bus and the capsule science. The capsule science consists of an entry payload that functions only during descent and the landed science that operates on the surface. The canister/adapter serves to attach the flight capsule to the flight spacecraft and to support the lander while maintaining its sterile condition.

- Flight Spacecraft. A flight spacecraft consists of a spacecraft bus, spacecraft propulsion, and a spacecraft science subsystem.

- Planetary Vehicle Adapter. A planetary vehicle adapter consists of all structure, cabling, and hardware located between a planetary vehicle in flight separation point and the associated points of attachment to the shroud.

2.3 PROJECT ORGANIZATION

Organization and management for the Voyager project can be described in terms of four levels as shown in Figure 2:

- Program direction
- Project management
- System management
- System implementation

Program direction corresponds to overall executive authority and control, which is vested in the Voyager Program Director, NASA Headquarters. Project management is delegated to the Voyager project office, which is either within NASA Headquarters or part of a NASA field center designated to have project management responsibility. The first level of activity below the project level is designated as a system. Management responsibility at this level is delegated to one or more NASA field centers. This responsibility is carried out through system management offices, each having cognizance over one of the Voyager system areas. Implementation of the various system elements is carried out by contractor and governmental organizations under the direction and management of the appropriate system management office.

The authorization for a project by NASA takes the form of a project approval document. Within the scope defined in this document, the Voyager Project Director has the overall responsibility for achieving the Voyager objectives and ensuring that the Voyager project is compatible with the programmed goals and resources. This involves

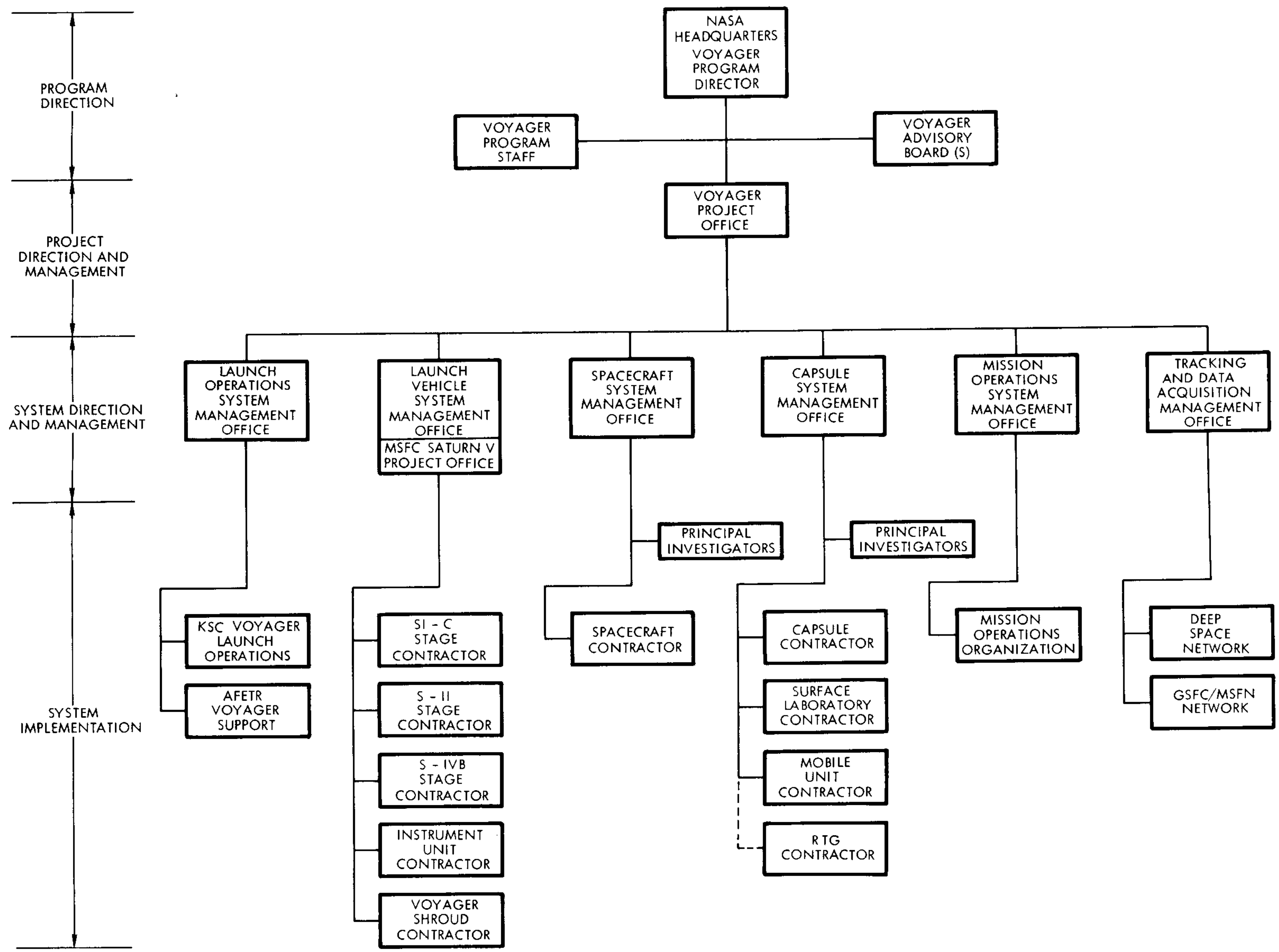


Figure 2. Voyager Project Organization

formulation of project objectives and policy guidelines, programming and allocation of resources, inter-project coordination, external relations, and overall project evaluation and direction. The director is assisted by the Voyager program staff and makes use of technical advisory boards as appropriate. He has overall responsibility for definition of the scientific program and selection of the associated principal investigators. Although the basic system management assignments are established by the project approval document, the detailed responsibilities are defined by the project development plan as approved by the director.

Project management is delegated to the Voyager project office, which consists of a Voyager project manager and his supporting organization. The manager is responsible for project-level management as well as project definition and technical direction above the system level. Project definition and technical control are exercised through mission specifications, intersystem interface control specifications, and other project planning and control documents. The project manager approves all system specifications and other major system planning documents issued by the system management offices.

A System Management Office (SMO) under the direction of a system manager is established for each of the six Voyager systems, as shown in Figure 2. Since a system corresponds to a first major subdivision of work below the project level, it is defined in keeping with administrative or contractual alignments representing direct responsibility for such work. This work breakdown for the Voyager project is indicated in Figure 2 by the association of organizational elements with each system management office at the implementation level.

In addition to the definition of primary system cognizance in keeping with project work breakdown, a different alignment of responsibilities along functional lines is needed to carry out launch operations and mission operations. Such support elements from one system function under the direction of another system as established by appropriate agreements between the affected SMO's and related administrative or contractual arrangements at the implementation level. For example, during planetary vehicle/shroud system operations, support is provided by the capsule contractor and shroud contractor to the spacecraft contractor, who has responsibility for such activities.

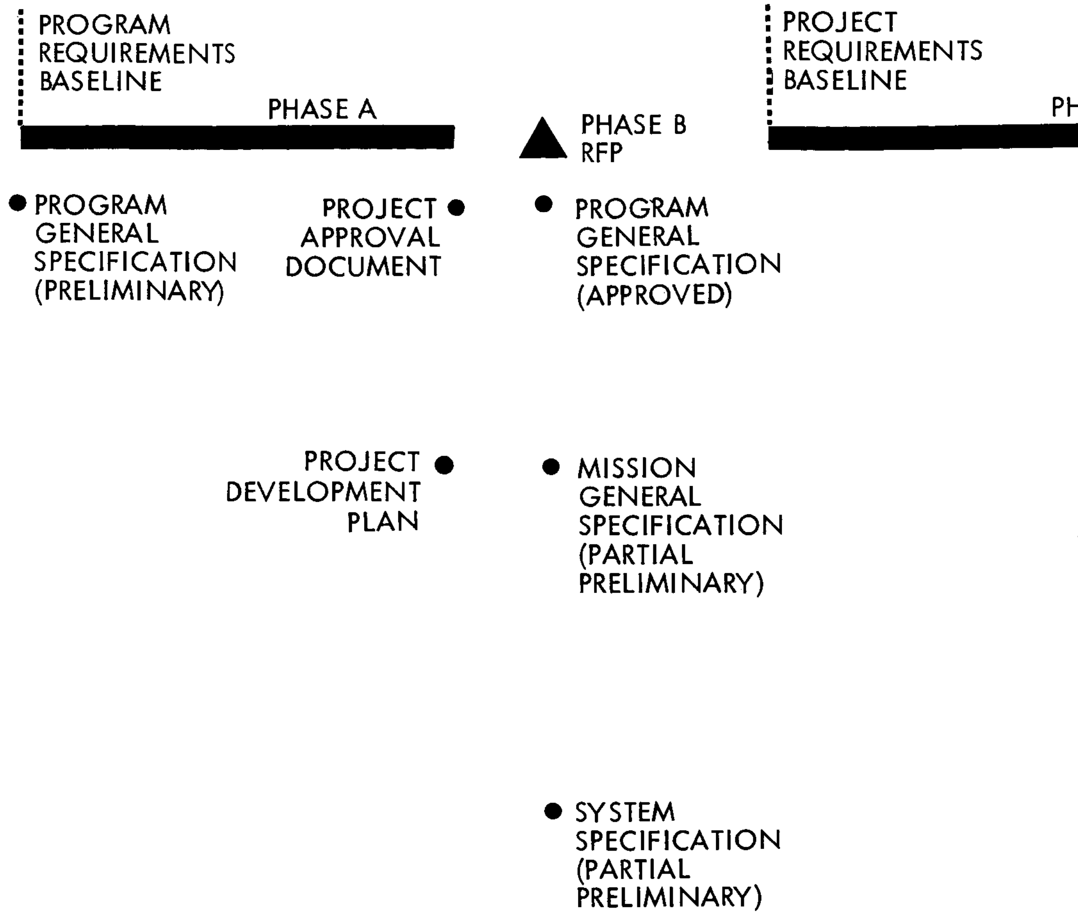
3. SCHEDULE

In keeping with NASA policy, the Voyager project will be carried out by a sequence of implementation phases, each defined to correspond to a specifically approved activity undertaken only after review and analysis of preceding work. In keeping with the phased implementation, formal baselines are established in sequence as illustrated in Figure 3 to allow review and control by various levels of project management.

The overall project flow and schedule for the three-generation program is shown in Figure 4. This figure clearly demonstrates the fact that only three distinct generations of Voyager flight hardware can be accommodated by the six launch opportunities. Operations at Mars do not begin until early 1974, following the 1973 launch, but production of the capsule system for the 1975 launch must already have started, by early 1973. Hence no opportunity will exist for modifications of the second Voyager based on data returned from the flight of the first. Although the preliminary design review for the second-generation laboratory and mobile unit occur before the 1973 launch, design and development for these systems overlaps the return of data from the 1973 laboratory by some six months, the critical design review being scheduled six months after the first has landed on Mars. Hence sufficient opportunity will exist to choose among alternate experiments and design approaches postulated during the second-generation Phase C and breadboarded during the early part of the following Phase D. It is clear, however, that the reaction to the initial results will be limited to selecting among previously identified alternatives, time is not available for preliminary design or defining experiments after the first results are obtained.

An illustrative inter-contractor critical area for pacing the entire project is demonstrated in Figure 4. The capsule system proof tests are scheduled to be completed by mid-1972 and these tests must be compatible with deliveries to the capsule bus contractor of proof test models for the surface laboratory, mobile unit, and RTG. These deliveries must occur as scheduled in 1971 to permit adequate checks and sufficient time to react to any interface problems uncovered. Hence the deliveries early in 1971 of the proof test models of the surface laboratory and mobile unit are milestones in the project that must be monitored and controlled to avoid delay in the important capsule proof testing.

Figure 4 also illustrates the substantial load that Voyager may place on the ground system. If flight equipment lifetimes are achieved in keeping with design goals, two orbiting spacecraft and two landers will need to be handled virtually continuously from 1974 on, and by 1979 or 1980 this load may double unless prior Voyagers are deliberately terminated as later ones reach Mars.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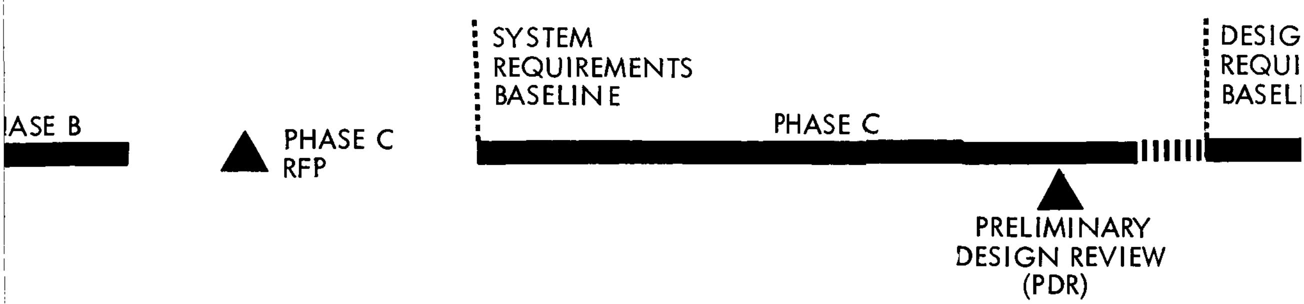
SYSTEM SPECIFICATION (PARTIAL PRELIMINARY)



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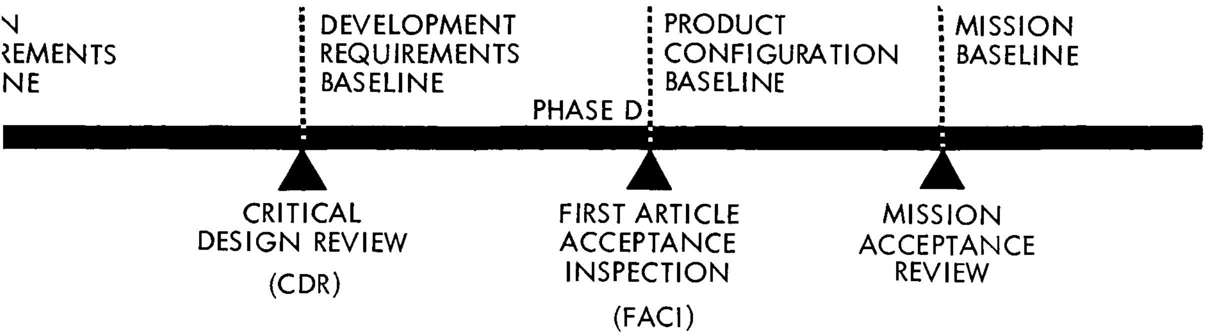

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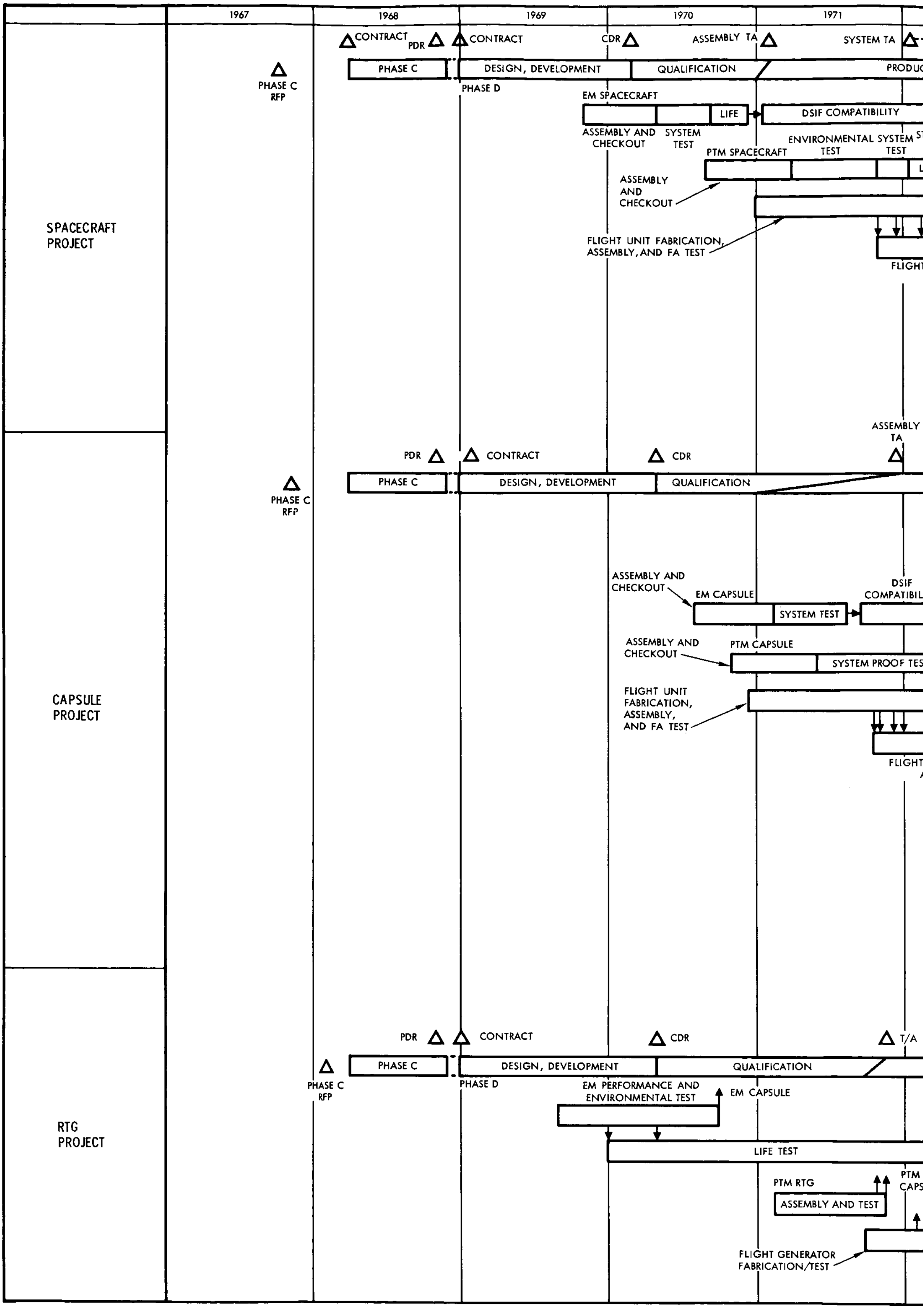
Figure 3. Project Sequence and Baselines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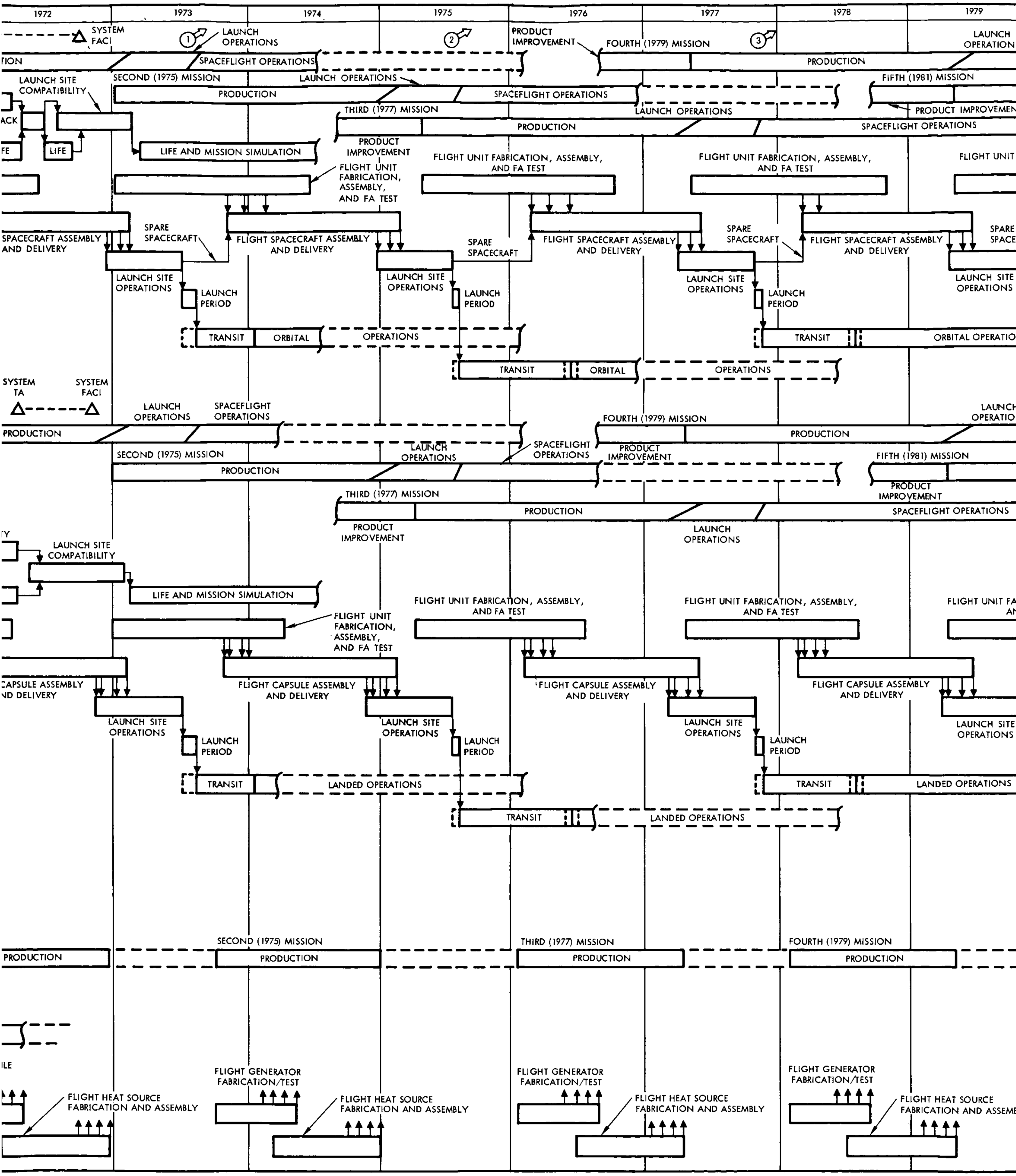
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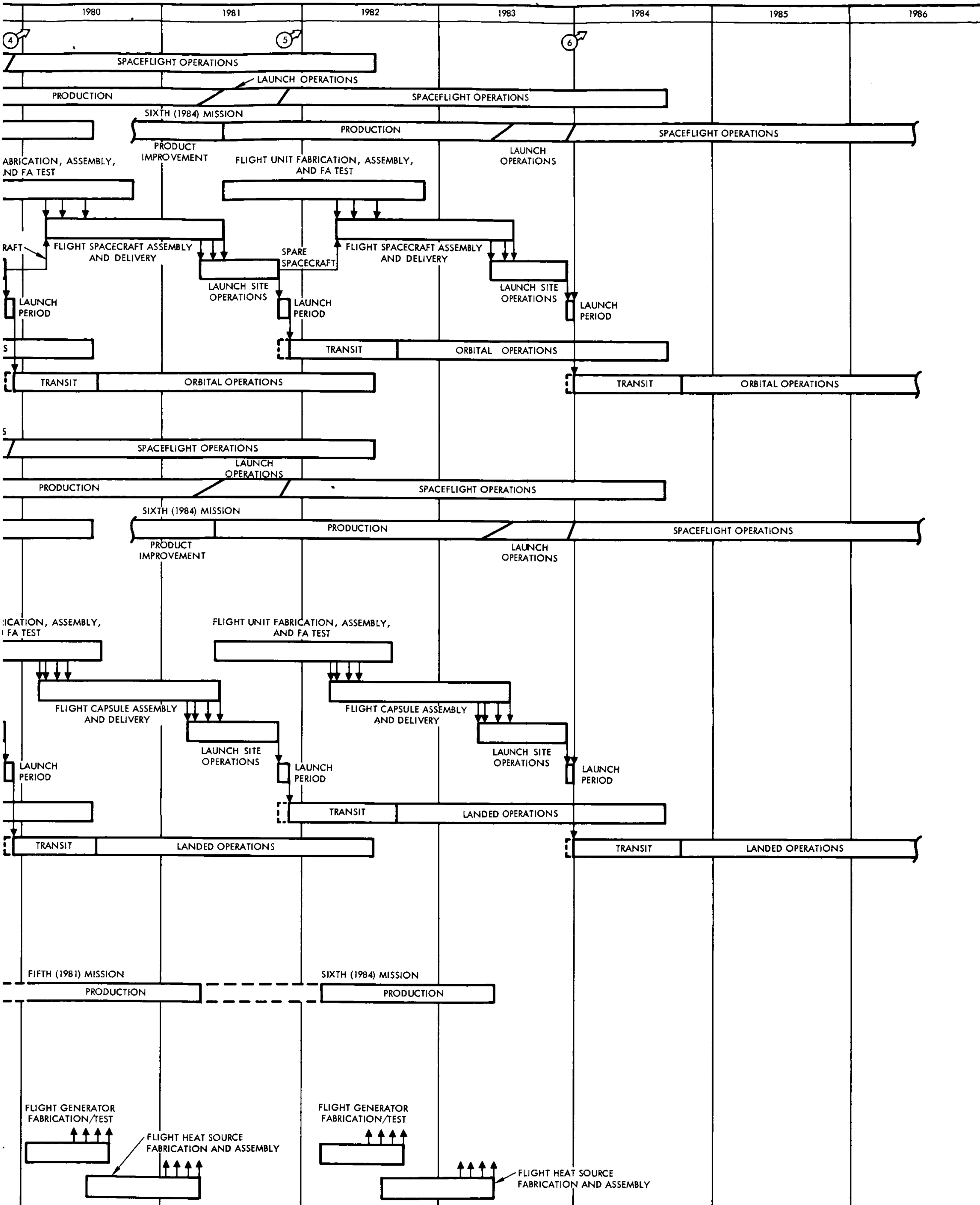
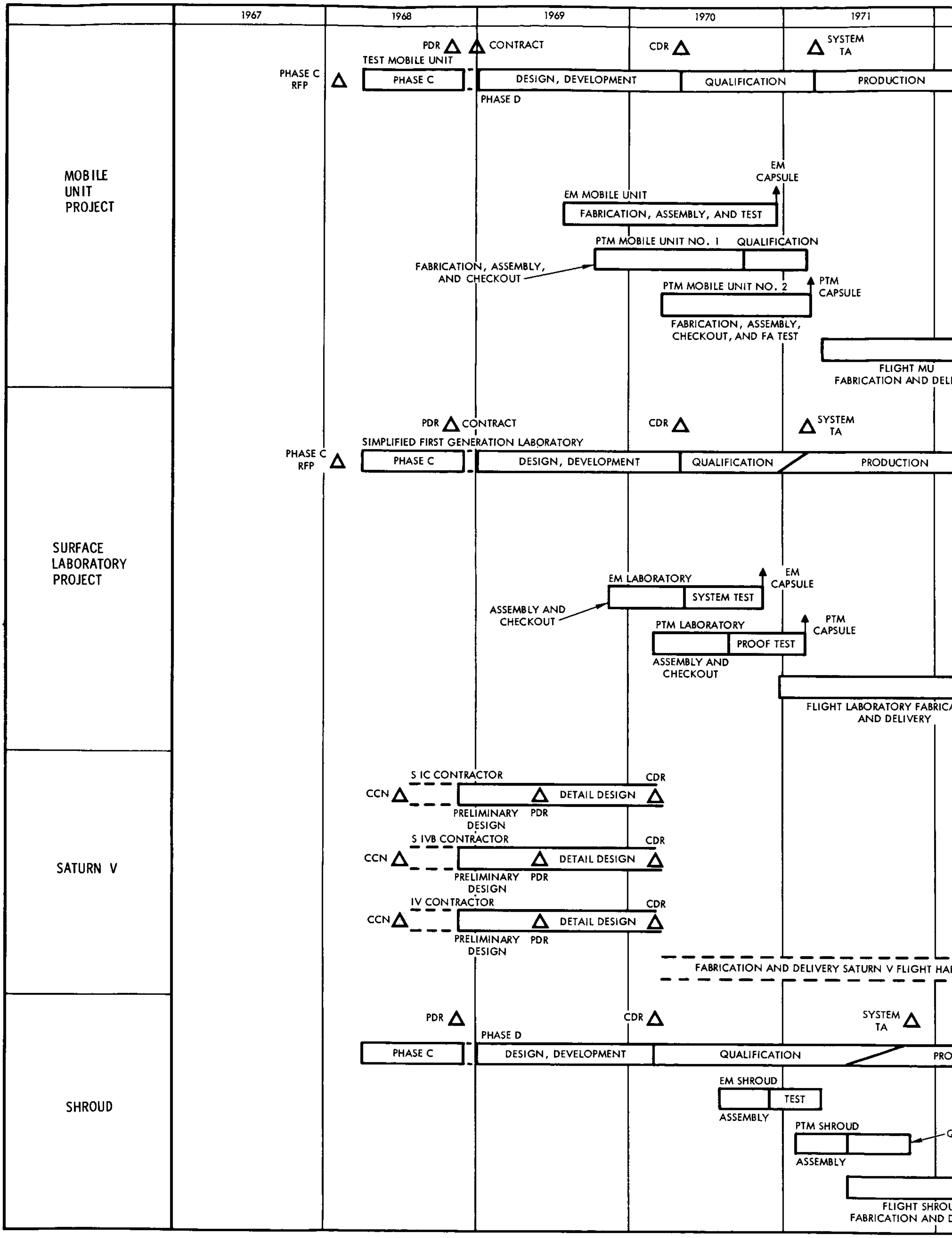


Figure 4. Voyager Project Flow and Schedule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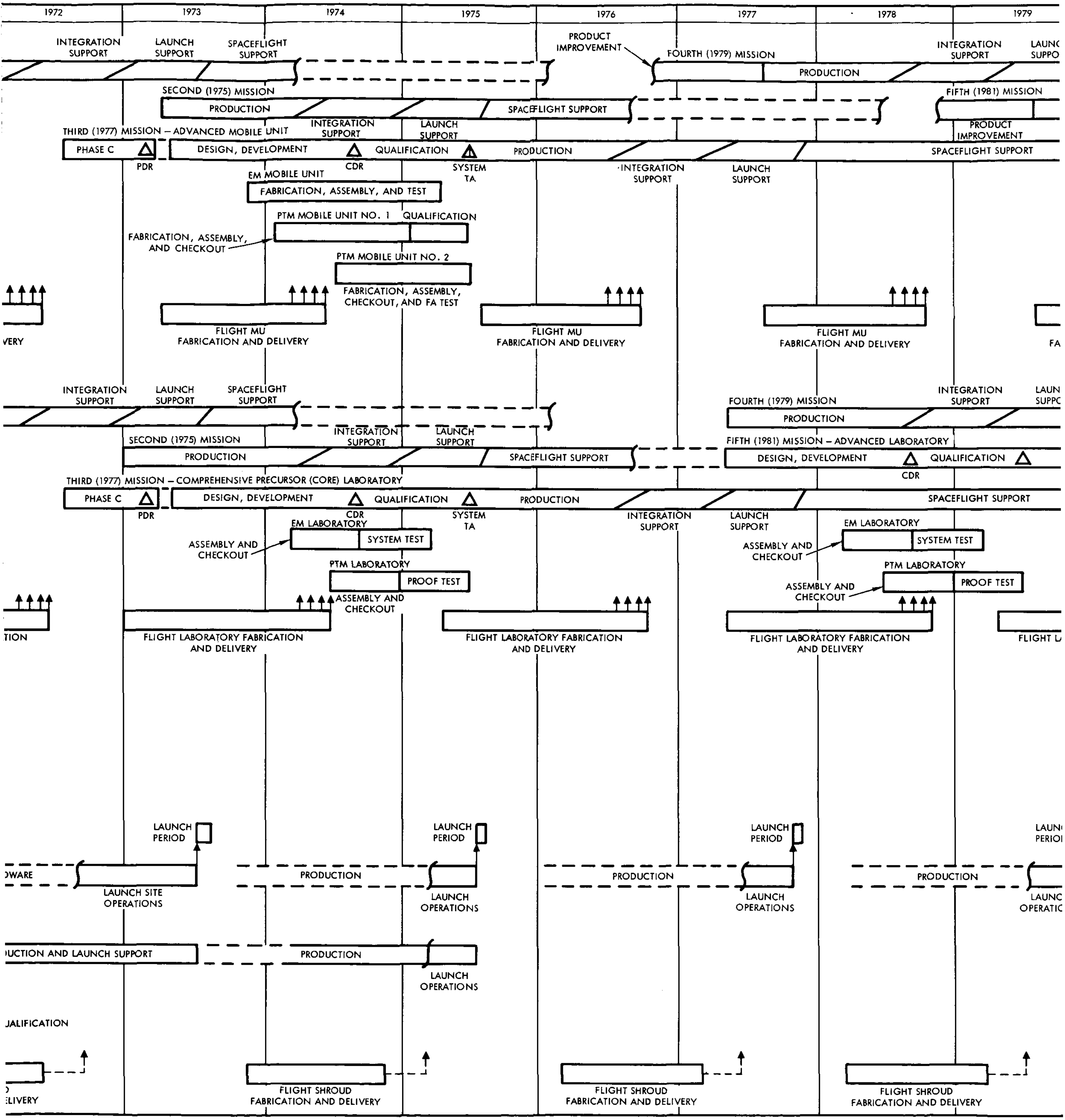

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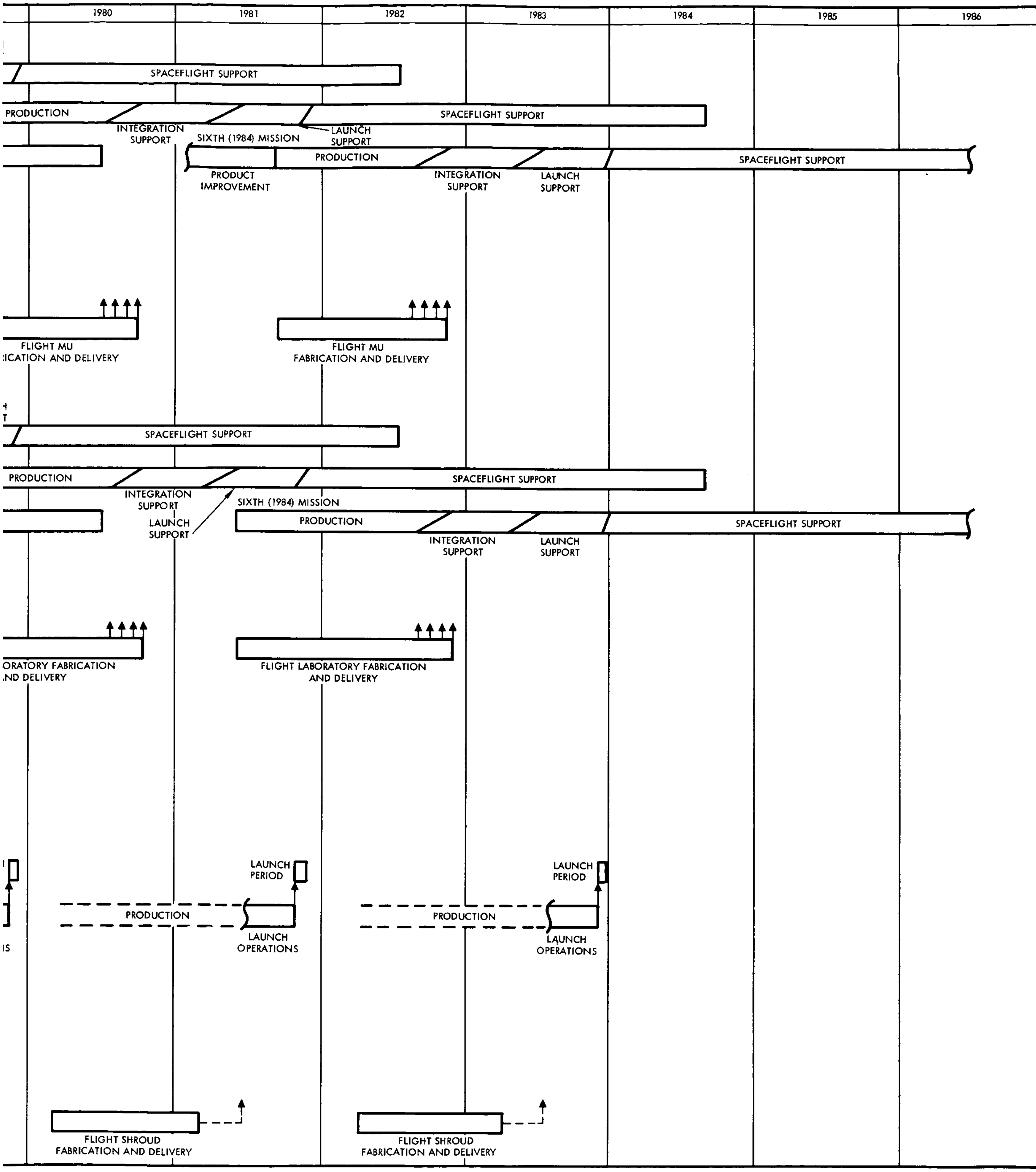


Figure 4. Voyager Project Flow and Schedule (Continued)

4. SPACECRAFT IMPLEMENTATION

The spacecraft system is implemented by the spacecraft contractor, under the direction and management of the spacecraft system management office, which in turn operates under the general cognizance of the Voyager project manager.

4.1 IMPLEMENTATION APPROACH

The approach to spacecraft implementation embodies these key features:

- Early design data from development test is gained by completing laboratory engineering model unit environmental tests and integrating the engineering model units into the spacecraft engineering model prior to final drawing release
- Early reliability data is available from engineering model and type approval test before initiation of proof test model (PTM) testing. In addition, spacecraft life testing will be conducted on the engineering model spacecraft and subsequently on the proof test model spacecraft
- Type approval environmental testing of units is complete prior to the start of spacecraft proof test model environmental tests
- Verification of final design by PTM tests is achieved six months before flight article spacecraft are committed to environmental tests
- During spacecraft assembly, the buildup and checkout of subsystems will be accomplished "off line", providing high confidence in integration of the subsystem into the spacecraft
- The spacecraft assembly and test spans include realistic operation spans with contingency spans applied in critical areas
- The equipment module and the propulsion module are integrated in parallel to increase physical access to the hardware and allow more operation time
- Time is available after delivery for additional testing prior to flight on the flight spacecraft, to increase confidence in flight performance

Schedule confidence is enhanced by the modular design concept. The modular design permits "off line" buildup of subassemblies (subsystem elements) and parallel buildup of the equipment module and the propulsion module. The concurrent operations conserve schedule time by reducing end-to-end span links and, in case of unanticipated problems, preventing adjacent interfaces from being changed by retaining decentralized assembly and test operation.

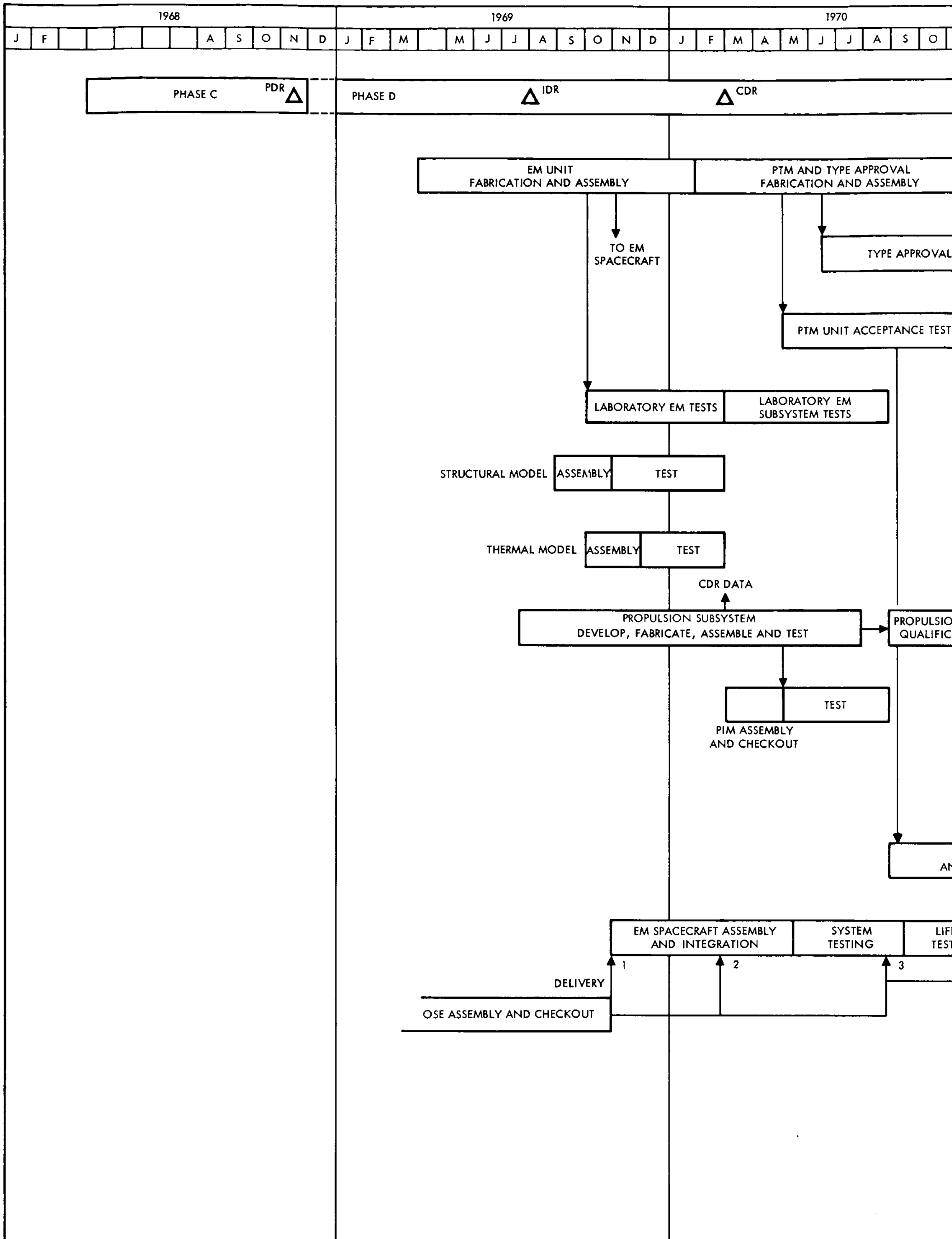
4.2 IMPLEMENTATION ACTIVITIES AND SCHEDULE

The gross spacecraft project implementation flow for all missions is shown in Figure 4 and in more detail for the initial mission in Figure 5. The project is initiated with the issuance of a Phase C RFP in November 1967. Contract award is assumed to take place by April 1968, with the preliminary design review in November 1968.

Phase C will include detailed system design of the selected spacecraft system concept and the fabrication and test of breadboard hardware of selected critical subsystems as necessary to provide reasonable assurance that the technical milestone schedules and resource estimates for the next phase can be met. Concurrent with this system effort will be design and analysis and revision of the various spacecraft project management and implementation plans in accordance with NASA requirements.

Under the direction of NASA, the spacecraft contractor will coordinate spacecraft interface requirements with those of other systems in the Voyager project. Final spacecraft intersystem interface requirements documentation will then be prepared and submitted to NASA for approval and issuance after the preliminary design review.

The subsystem engineering effort will consist of an initial updating of subsystem design data and the initiation of design studies and analyses in accordance with the directions of the system engineering design team. The subsystem groups will also define the requirements for critical breadboard testing.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LABORATORY EM TESTS
LABORATORY EM
SUBSYSTEM TESTS
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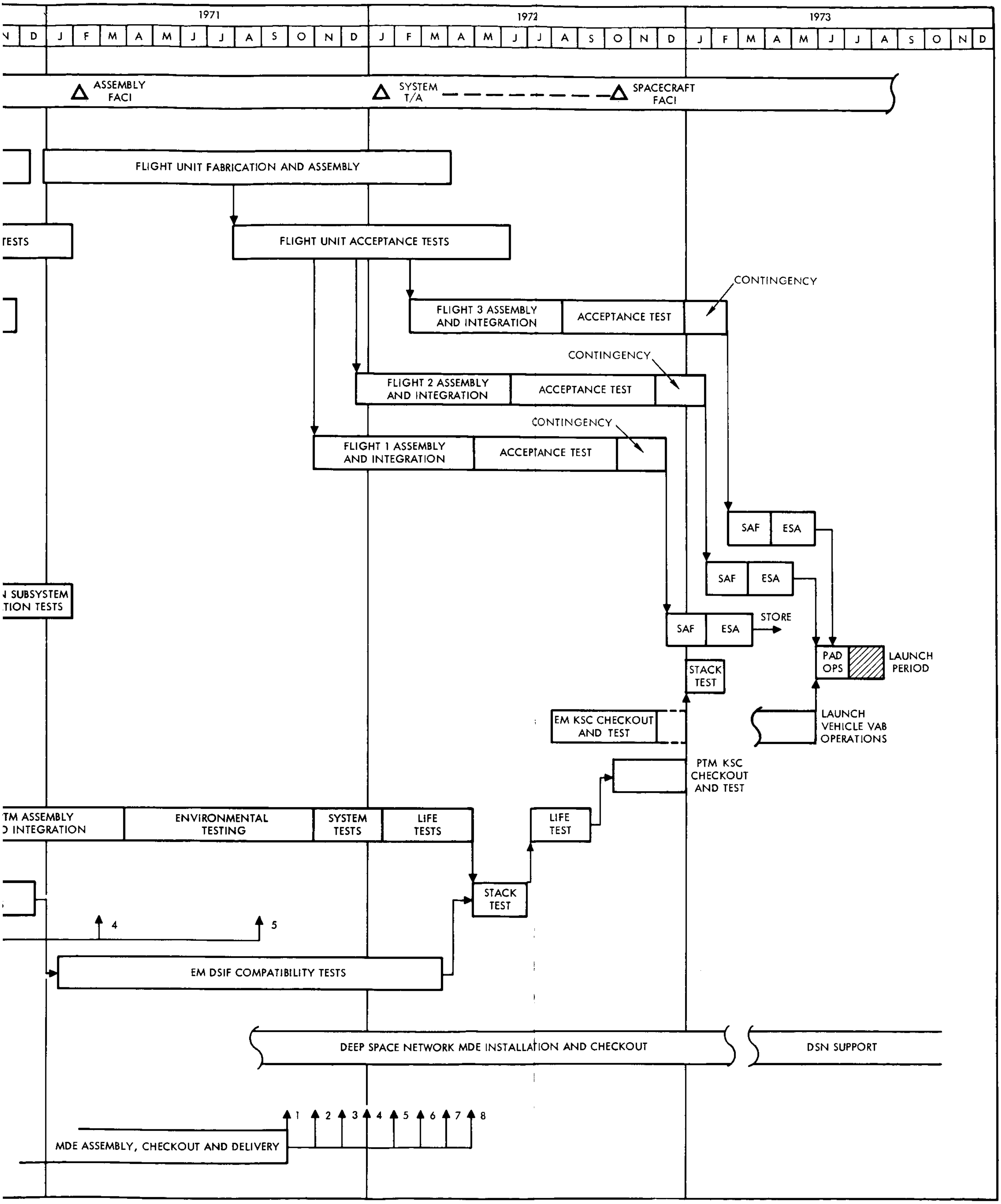


Figure 5. Spacecraft Project Flow for Initial Mission

Phase D is to be initiated in January 1969. At that time detailed design of the overall spacecraft system will be started. This will include the design of engineering models, test facilities, soft tooling, and special manufacturing devices. Design of OSE to support the assembly and checkout of all flight-configured hardware will also be undertaken. Finally, detailed designs of flight-type articles and MDE will be initiated and culminate in a series of subsystem critical design reviews in February-March 1970, allowing over 2.5 years for fabrication, type approval testing, and delivery of the first flight article. Flight article unit fabrication starts in January 1971 and spacecraft qualification is completed in January 1972.

System FACI, as finalized with acceptance of the first flight article, will be completed by November 1972, approximately nine months before the launch. Three flight-configured spacecraft (two plus one spare) will be fabricated, assembled, checked out, and acceptance tested at the spacecraft contractor's facility prior to shipment to KSC. All three systems will be shipped to KSC during the period December 1972 to February 1973.

The spacecraft system will remain essentially standardized for the additional five missions of the reference program. Modifications to the spacecraft for product improvement and new science or capsule integration requirements will be the pacing activities during these follow-on mission phases.

The scheduling of major activities is generated by first defining the time before launch when it is necessary to initiate assembly and checkout of the first flight spacecraft. The time required has been derived from a detailed, elapsed-time analysis of the tasks involved in launch site operations, shipping, flight acceptance testing, and assembly and checkout operations. The next step defines the delivery date for each subsystem in terms of need date during the spacecraft assembly and checkout sequence. In turn, by accounting for the subsystem flight acceptance testing and manufacturing span, the start date for the manufacturing of each flight subsystem is defined. Thus the need dates for flight hardware drawing release are established.

The start of proof test model (PTM) assembly and checkout operations has been determined by scheduling completion of the major portion of the PTM type approval testing (i.e., magnetic, vibration, acoustics, and space simulation testing) a suitable time prior to completion of assembly and checkout of the first flight spacecraft. This constraint then establishes the delivery dates for the PTM subsystem assemblies.

The drawing release dates for the fabrication of the subsystem type approval and PTM assemblies has been set for each subsystem by the condition that subsystem type approval testing must be complete prior to start of PTM environmental testing. This establishes the manufacturing drawing baseline dates (hence CDR) for each subsystem. The CDR date then forms the basis for the subproject engineer to establish Phase D implementation plans and schedules.

4.3 SALIENT FEATURES AND IMPLEMENTATION ALTERNATIVES

In considering implementation alternatives, the basic purpose is to develop an understanding of significant aspects concerning implementation of the Voyager project. The discussion of salient features and the associated rationale brings out such information, even though explicit alternatives (other than the elimination of these features) may not be easy to identify. Thus such discussions are included below.

4.3.1 Spacecraft Standardization and Sizing

The fundamental set of alternatives affecting spacecraft implementation relates to project definition. In particular, the use of a standardized spacecraft rather than an evolving design leads to dramatic simplification of the total program, since there is then only one major spacecraft development cycle. This standardization is possible because spacecraft design does not depend critically on refinement of Mars data. However, standardization will not be realized unless the initial configuration fot the spacecraft provides adequate payload performance in tankage and structural capability to support the later, upgraded capsule systems. The problem, of course, is in knowing at the outset what spacecraft sizing to provide. Considering the historical situation in which exploration requirements have tended to outstrip early estimates, it appears appropriate to size for the maximum payload in Mars orbit consistent with Saturn V flight performance.

4.3.2 Data Transmission Capability

Another aspect of project definition affecting spacecraft implementation is the requirement for data transmission. The high data rate of the reference approach has been selected in keeping with the comprehensive Mars exploration postulated for the study. Such an approach makes possible an extensive Mars mapping capability, at the expense of some complexity to the spacecraft itself and considerably more complexity to the ground data handling system. The preliminary investigations of this study have indicated such an approach is feasible, although further studies are required to assess the overall cost effectiveness of such an approach. The projected long stay times in orbit and the many missions tend to reduce the requirement for data rate. On the other hand it will be possible to exchange any excess data transmission capability for a reduction in coverage by the ground stations. The high data rate initially also provides for comprehensive mapping early in the program, which is important for effective definition of the follow-on missions.

4.3.3 Spacecraft System Engineering

The reference approach calls for a considerable amount of spacecraft system engineering to be provided by the contractor, operating under the cognizance of the spacecraft system management office. This does not represent a duplication of the system engineering carried out by the SMO, since the emphasis for the SMO is intersystem and mission-oriented. In contrast, the emphasis for the contractor is intrasystem, working to well-defined overall system and intersystem interface requirements. The magnitude and complexity of the Voyager program indicate that such a contractor role is appropriate.

4.3.4 Science Integration

Another salient feature of the reference approach relating to the assignment of contractor responsibilities has to do with science integration and associated equipment responsibilities.

The implementation of spacecraft science involves both intersystem and subsystem considerations. The relation between the spacecraft contractor and the principal investigators is analogous to an intersystem interface in that the principal investigators have independent contracts with NASA. At the same time, the experiment equipment as well as other spacecraft science payload elements have a complex and intimate relationship to the spacecraft hardware akin to that of a spacecraft hardware subsystem. This relationship is the key feature and requires a comprehensive role on the part of the spacecraft contractor for integration of such equipment. As a corollary, such major elements as the planetary scan platform, the fixed science packages, and the science data automation equipment should be developed by the spacecraft contractor as part of the spacecraft bus rather than supplied as GFE.

For most experiments in the reference payload there is a particular central science instrument. It is expected that the associated principal investigator will supply such equipment to NASA, and this will in turn be delivered to the spacecraft contractor as GFE. In the case of the imaging system, however, the equipment represents a complex engineering and development task, and for the reference project approach will be supplied by the spacecraft contractor. The experiments which utilize the imaging system will then be defined by selected principal investigators, who will participate in defining the requirements for the imaging system and its design characteristics. They will of course be concerned with how the system is used during the mission. This includes selection of filters, resolution, and areas to be photographed, etc., and they will interpret the pictures obtained for scientific context.

4.3.5 Engineering Model Hardware

The use of engineering models is proposed for the following reasons:

- Equipment almost identical to flight hardware can be produced with preliminary tooling early in the schedule

- Test procedures can be checked in an informal atmosphere

- Design changes can be incorporated before the critical design review
- OSE and computer programs can be debugged during the EM cycle
- Time and expense of EM tests will be compensated for by smoother flow of official TA and FA tests

The first engineering model, or laboratory engineering model, may be made in engineering laboratories and does not require potting. The initial tests on this model are the same as for breadboard tests. Thus, when breadboards are not needed for design purposes, the breadboard tests may be replaced by engineering model tests when the schedule permits. Engineering model tests also include electromagnetic interference and magnetics. After assembly-level tests, the engineering model assemblies are integrated into a subsystem for subsystem-level tests. This EM subsystem may replace the breadboard subsystem for continued monitoring and tests.

The second engineering model of an assembly is used for the engineering model spacecraft. This model is made in the manufacturing area and is equivalent to flight hardware with respect to conformal coating and potting. The test program for this model is coordinated with the program for the first model so that a complete spectrum of environments is covered by the two models. For example, vibration to TA levels can be performed on the second model since the parts are potted.

4.3.6 System Test Approach

System testing of the engineering model spacecraft is performed primarily as a system compatibility and facility validation task, but it will also be used for environmental and life testing. It will be used to verify OSE design, debug procedures and operations, and train personnel. The EM will be used at Goldstone to perfect the mission operation sequence and to verify compatibility with the Deep Space Network. The EM spacecraft and the proof test model spacecraft will be used to validate launch site procedures, equipment and facilities.

The system testing of the PTM is aimed at system design verification and environmental type approval of flight type hardware. It will also serve to further debug procedures, operations, and OSE and to train personnel. Any design changes made as a result of the EM system tests will be specifically checked. The PTM will also be used to perform reliability life tests.

The acceptance testing of the flight spacecraft system is performed primarily as a workmanship verification. The major design problems will have been resolved by the EM and PTM spacecraft.

During system testing, the electrical interfaces between the spacecraft and the OSE will be minimized. Test cables constitute a nonflight configuration and can cause abnormal system operation as well as injecting unwanted noise. The goal will be to operate the spacecraft in a configuration as close as possible to a flight configuration. Sufficient spacecraft telemetry will be provided to isolate faults to the provisional spares level and to enable verification of command status. Certain commands are required for testing and will aid in keeping hardline use to a minimum. These commands will primarily be used to check redundant system operation.

Wherever possible, system test stimulation (external stimuli used to excite flight equipment, usually having only a mechanical interface with the spacecraft) will be used, rather than simulation (signal injection), to perform an end-to-end system test. The same stimuli used during system tests will be used at the subsystem level. However, the subsystem test may incorporate additional stimulation or simulation.

4.3.7 Telemetry Usage for Test

The spacecraft test approach is to be based on making maximum use of telemetry for ground checkout, to minimize the number of hardlines to the spacecraft, and to allow testing in a mode more closely approximating the flight configuration. This policy requires allocation of sufficient telemetry to isolate faults to the provisional spares level. Analog telemetry functions are to be sampled at a sufficiently high rate so that all system parameters can be adequately evaluated, which may require a commutator speedup mode for ground test.

Provisions to verify receipt and execution of all commands as well as current command status is to be provided via telemetry. This is to include delayed commands sent to storage in the computer and sequencer as well as the direct commands sent via the command subsystem.

4.3.8 Degree of Automation for OSE

The need for a computer in the system test complex has never been at issue, but rather, given a general-purpose computer, the question is what level of emphasis should be placed on manual versus automated approaches to test sequencing, patching of OSE measuring and stimulation equipment into test configurations, and logging test measurements and evaluating them for status presentations.

A number of subsystem and system test parameters to be considered with respect to the choice of automatic versus manual control, as shown in Table 1. In general, the comparison indicates that automatic checkout is superior to manual in that the testing performed is faster (encouraging more exhaustive and more frequent testing), more dependable with respect to the way it is performed and recorded, and less likely to result in spacecraft damage from procedural errors. It is inferior in that unexpected conditions are more likely to go unrecognized, total program costs attributable to system test are likely to be higher (in spite of saving test man-hours), and automatic test equipment is more difficult to produce on a short schedule. Equipment reliability (as distinct from total test reliability) is worse for the automatic equipment, by virtue of the difference in component population, although measures can be taken to combat this problem by such means as backup modes and conservative logic.

Although a quantitative assessment appears impractical, if more tests of a meaningful nature are performed more frequently, and more data is gathered permitting better statistical and trend analyses, it appears reasonable to assume that chances for mission success are improved. In addition, checkout and replacement times during launch operations will be reduced to enhance chances of meeting the launch period constraints. It is on this basis that automatic checkout has been selected for the reference STC configuration.

Table 1. Automatic Versus Manual Testing Tradeoffs

Parameter	Automatic	Manual
Testing speed	Limitations in this case will only be transient settling times in spacecraft and OSE, and in command times when RF commands are used.	Limited by operator speed—much slower than automatic.
Test condition repeatibility	Limited only by stability of test equipment. Requires configuration control of software to same degree as hardware.	Limited by care exercised by operator. Can be controlled by discipline in use of written procedures
Requirements on operating personnel	Reduces actions required, but frequently encounters resistance to use in place of familiar manual methods, especially if initial integration encounters problems.	Increases number of personnel required, but requires shorter time to build up confidence of experienced personnel in test methods. Test personnel qualifications required are higher.
Test documentation	Excellent, if analysis preceding software design is accurate in predicting operational conditions and procedures.	One of the major difficulties of manual test systems. Discipline in test result reporting must be constantly monitored. Tendency not to record transient or unexplainable events.
Flexibility	In practice less flexible than manual because of additional problem of unforeseen effects of program changes.	Difficulties in implementing changes in test procedures or test equipment dependent on change control procedures in effect.
Spacecraft damage potential	Little danger. Reaction time shorter than manual and shutdown procedures more reliable.	Depends entirely on skill, alertness, and reaction time of operators. Reaction time inevitably longer than automatic.
Fault isolation ability	Much faster, but accuracy depends on skill in analysis of failure modes and symptoms, which is done in parallel with spacecraft equipment development.	Depends on skill of operators, but improves rapidly with time, as operators gain experience with spacecraft.
Reliability	Equipment reliability is worse because more equipment of greater complexity is involved, but total test process reliability may be better because of reduced opportunities for human error.	Equipment reliability better because equipment is simpler, but fault may go unrecognized longer because selfcheck is not automatic. Human error a greater problem.
Recognition of unexpected conditions	Depends entirely on skill of system designer—usually system is limited in this respect.	Depends on skill and alertness of operators, but normally much better than automatic system.
Development cost	Substantially greater; software costs can equal computer equipment costs.	Less, expecially if tests can be configured to use commercial equipment.
Total program cost	Higher, but difference from manual reduced by lower testing time and fewer operating personnel.	Probably lower than automatic, in spite of increased man-hours and level of personnel per test, unless number of spacecraft is large.
Development schedule	Longer, and more difficult to compress, because people needed are more skilled and must be versed in total-system details. Integration with spacecraft normally takes longer.	Tends to be more easily separable into parallel segments, and design is less critically dependent on exact test procedures to be used.

4.3.9 Propulsion Interaction Testing

A propulsion interaction test can take any of the following three forms:

1) Support a structural model of the spacecraft in an altitude chamber on soft mounts and measure equipment response. This test is used to establish equipment environment as well as to verify that there are not propulsion system structural interaction problems.

2) Soft mount a structural spacecraft in an altitude chamber complete with operating equipment and fire the engine.

3) Soft mount the spacecraft in an altitude chamber with sufficient angular freedom to conduct control system compatibility tests.

Tests (1) and (2) are similar except that (2) is an actual demonstration using operating components, whereas (1) requires extensive vibration measurement and data analysis as well as equipment qualification testing. Both provide adequate investigation of propulsion-structure interactions. Such interactions are characterized by self-excited longitudinal sinusoidal oscillations, generally caused by coupling between the feed system, engine, and vehicle structure. Approach (1) is recommended because it can be accomplished earlier and is simpler and less expensive.

Test (3) was used on the Mariner program by mounting the spacecraft on bungees and firing the engine with an active flight control system. On most other programs this concern has been satisfied using subsystem transfer function tests such as control system servo-loop and modal survey structural tests. For the large Voyager spacecraft, the difficulties of test operation are perhaps greater than the design problem being investigated. Also the compromise necessary in the 1 g field related to sloshing frequencies as well as the mount requirements require considerable post-test analysis and make a full-scale Voyager test undesirable. However, an air-bearing test rig developed for OGO and already in existence may make a scale model test attractive.

4.3.10 Thermal Model Testing

The objective of a thermal model test is verification of the spacecraft thermal analysis and design. For the Voyager spacecraft the test could be conducted on a system or a subsystem level.

A system level test requires a complete thermal model of the flight spacecraft; a subsystem level test requires sectioning of the flight spacecraft into components having well-defined thermal boundary conditions. For a subsystem level test program the spacecraft would be sectioned into the following five major grouping of components:

1) The main compartment including associated structure and a simulated solar array

2) The planetary scan platform, including its gimballing system

3) Antenna systems, which would individually be tested along with associated gimballing systems

4) External experiments, which would be individually tested

5) The solar array

The system approach to thermal testing utilizing a thermal model and solar simulator is technically superior to the subsystem approach, and has been selected for the reference approach, although more expensive. It also requires the availability of the large vacuum chamber that is also required for spacecraft qualification and acceptance testing, so will need to be carefully scheduled.

4.3.11 Magnetic Testing

The reference approach requires spacecraft magnetic testing both for development, type approval, and flight acceptance. However, the magnetic properties control program is based on comprehensive analytical modeling supported by component tests. Experience with the Pioneer spacecraft, which had a stringent magnetic control requirement, has indicated the modeling approach to be quite valid. Hence significant reduction in magnetic testing of the Voyager spacecraft appears possible. In particular it may be possible to eliminate this testing for flight acceptance.

4.3.12 Reliability Testing

Reliability testing on Voyager is based upon the maximum utilization of test data generated throughout the program, supplemented by special testing in areas considered to represent potential reliability problems. Specifically, the approach consists of:

- Design of developmental tests to assure generation of appropriate reliability data
- Utilizing units which have completed type approval tests to generate life test data for time-sensitive equipment
- Developing a stress-test program for one or two units representing potential problem areas as new or significantly modified designs, representing new applications, past experience, mission criticality, etc.

A classical reliability test program involving formal statistical verification of reliability requirements has been rejected as too expensive and time consuming.

5. CAPSULE IMPLEMENTATION

5.1 CONTRACTOR ROLES

The central role for capsule system implementation is carried out by the capsule contractor. The landed science payload elements are each separately implemented by the surface laboratory contractor and the mobile unit contractor, and the RTG system is also implemented by a separate contractor. All of the elements are integrated into the capsule system by the capsule contractor. All of the contractors operate under the direction and management of the capsule system management office, which in turn operates under the general cognizance of the Voyager project manager.

The capsule SMO is responsible for establishing the capsule bus-surface laboratory, capsule bus-mobile unit, capsule bus-RTG, and surface laboratory-mobile unit interfaces. In this interface definition the capsule contractor plays a major support role, because of his responsibility for integration of the surface laboratory, mobile unit, and RTG into the capsule system.

The elements associated with the total capsule project segment are covered briefly in Section 2.2. The project segment under contract to the surface laboratory contractor is designated as the surface laboratory project. The associated project breakdown covers the stepwise laboratory development of the reference project approach, which includes the following tasks:

- Provide surface laboratory flight hardware, which includes deployable sample acquisition devices, processing and handling equipment, deployment mechanisms, and other support hardware and structure into which the landed science experiment equipment is integrated
- Provide science support flight and ground hardware, and integrate experiments into the surface laboratory
- Provide developmental models, spares, software, and OSE associated with the above

- Assist in achieving compatibility with the mobile unit and with the capsule bus

- Participate in preflight and mission operations in regard to the surface laboratory

The project segment under contract to the mobile unit contractor is designated as the mobile unit project, and includes the following tasks:

- Provide mobile unit flight hardware and the associated models, spares, software, and OSE

- Assist in achieving compatibility of the mobile unit with the capsule bus

- Participate in preflight and mission operations with respect to the mobile unit

The project segment under contract to the capsule contractor is designated as the capsule project, and includes the following tasks:

- Provide capsule bus and canister flight hardware and the associated models, spares, software, and OSE

- Provide science support flight and ground hardware and integrate the surface laboratory, mobile unit, RTG, and entry science payload with the capsule bus

- Provide preflight operations for the capsule and participate in the integration of the capsule with the spacecraft and in space vehicle prelaunch operations

- Participate in mission operations with respect to capsule project hardware

The RTG elements which are part of the capsule system are provided to the Voyager project by the AEC. The project segment under contract from the AEC to the RTG contractor is designated the Voyager RTG project, and includes the following tasks:

- Provide RTG flight hardware and the associated models, spares, software, and OSE

- Assist in achieving compatibility of the RTG with the surface laboratory and the capsule bus

- Participate in preflight and mission operations in regard to the RTG

This section discusses the role of the capsule contractor, providing an overall framework for the total capsule system implementation. Sections 6, 7, and 8 discuss RTG, surface laboratory, and mobile unit implementation.

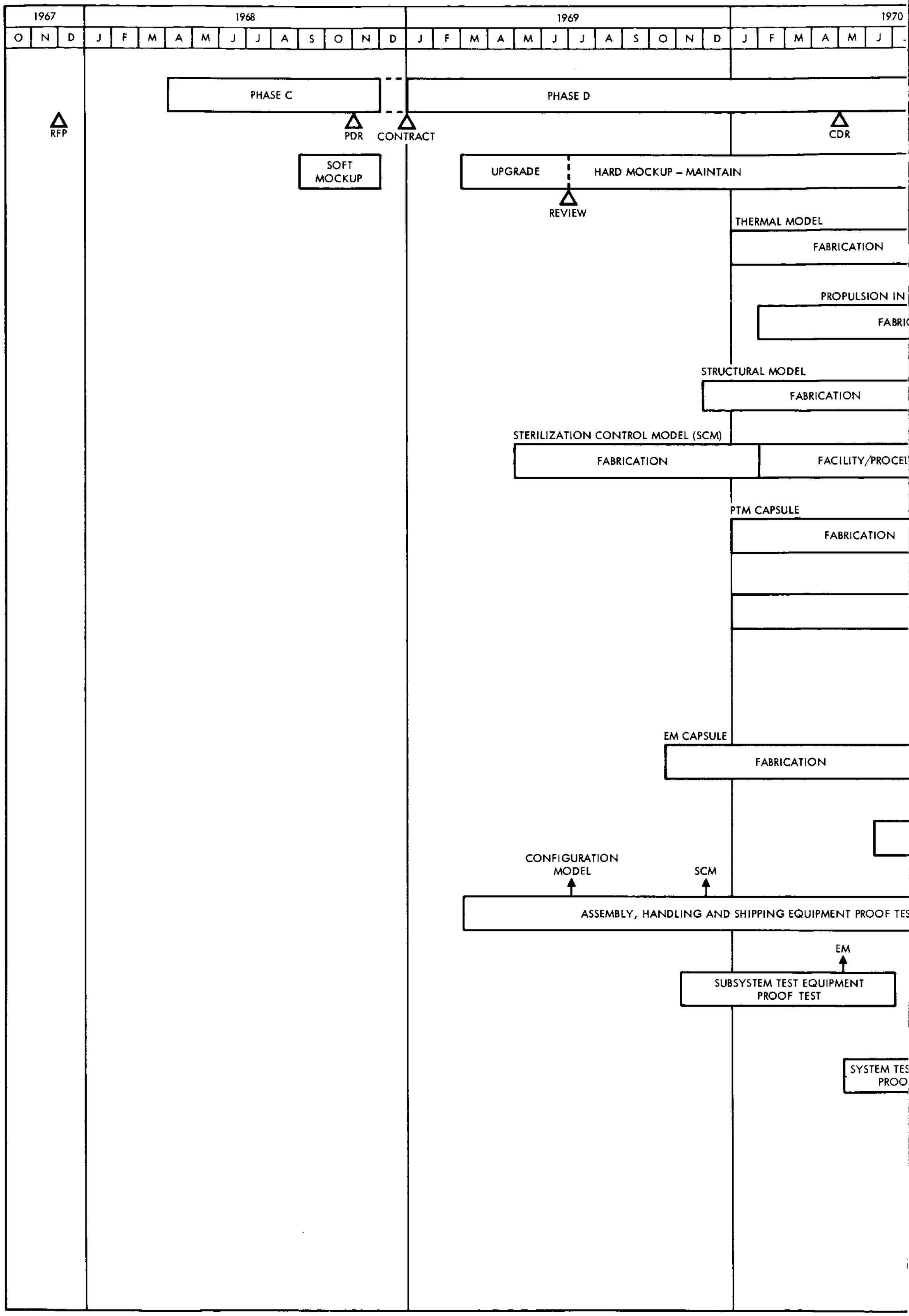
Within the resources of the Voyager Support Study it has not been possible to carryout a preliminary design and develop the related implementation definition for a capsule system. However, a cooperative data exchange between TRW and the Grumman Aircraft Engineering Corporation was arranged to make available data from the extensive work done by GAEC in this area, and capsule implementation definition for the study is founded in large measure on this data.

5.2 IMPLEMENTATION APPROACH AND SCHEDULE

The gross project flow for the capsule system was shown in Figure 4; it is given in more detail for the initial mission in Figure 6. The schedule assumes Phase B activities completed by October 1967 and Phase C for the capsule bus initiated with the issuance of an RFP by December 1967. Selection of a capsule contractor should be completed by April 1968. The overall schedule and major activities during this phase will be quite similar to those for the spacecraft system. However, because there will be three intrasystem associate contractors, it is anticipated that the interface control documentation activities for the capsule contractor will be more extensive than for any other major Voyager program associate contractor.

Because of the more complex interactions among the equipment constituting the capsule system and because of the more stringent sterilization requirements, the capsule development cycle will require more test activities and more time than that for the spacecraft. The major development test models required to support capsule development leading to formal qualification testing of capsule hardware are as follows:

- Configuration model
- Sterilization control model (SCM)
- Structural model (SM)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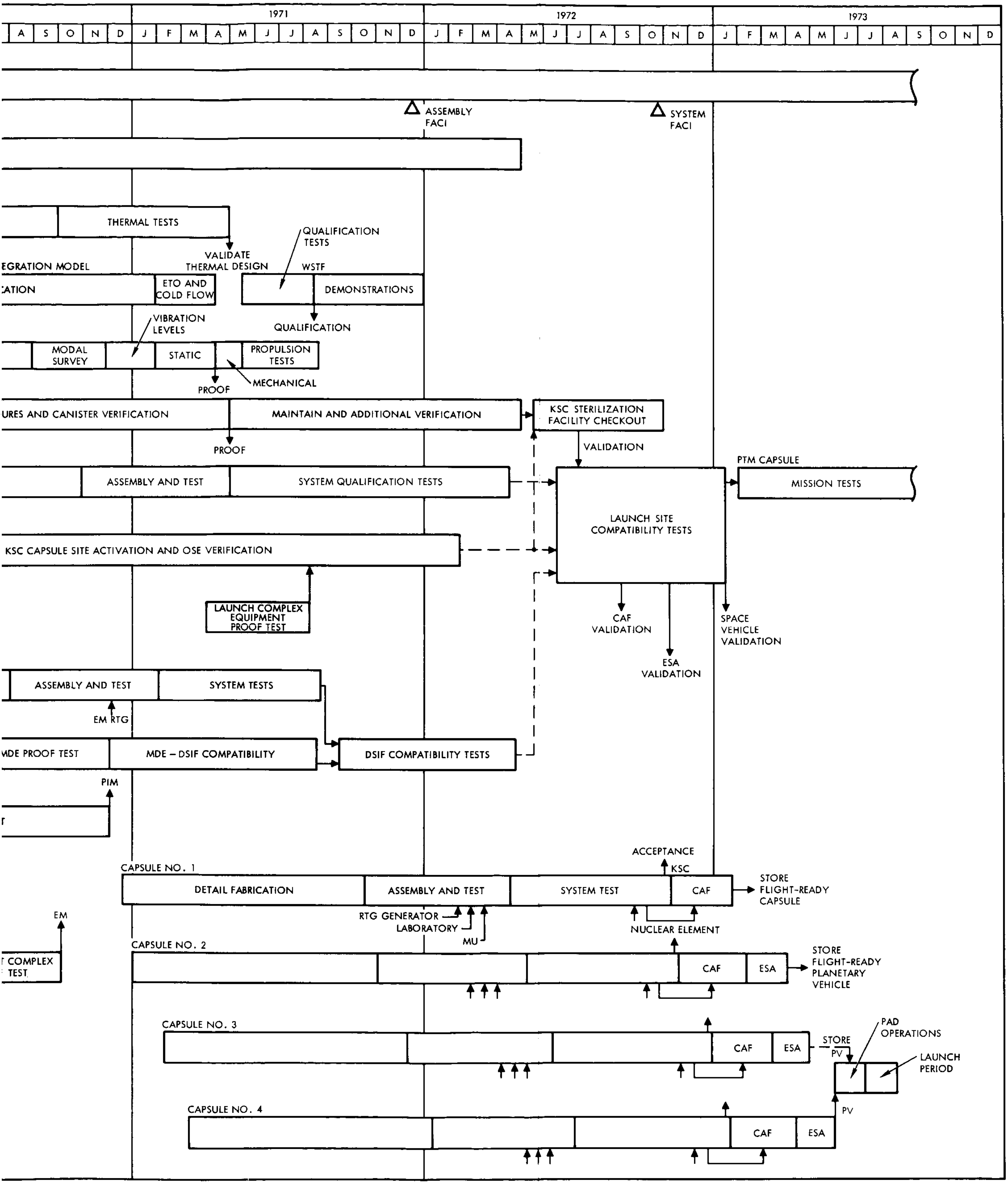
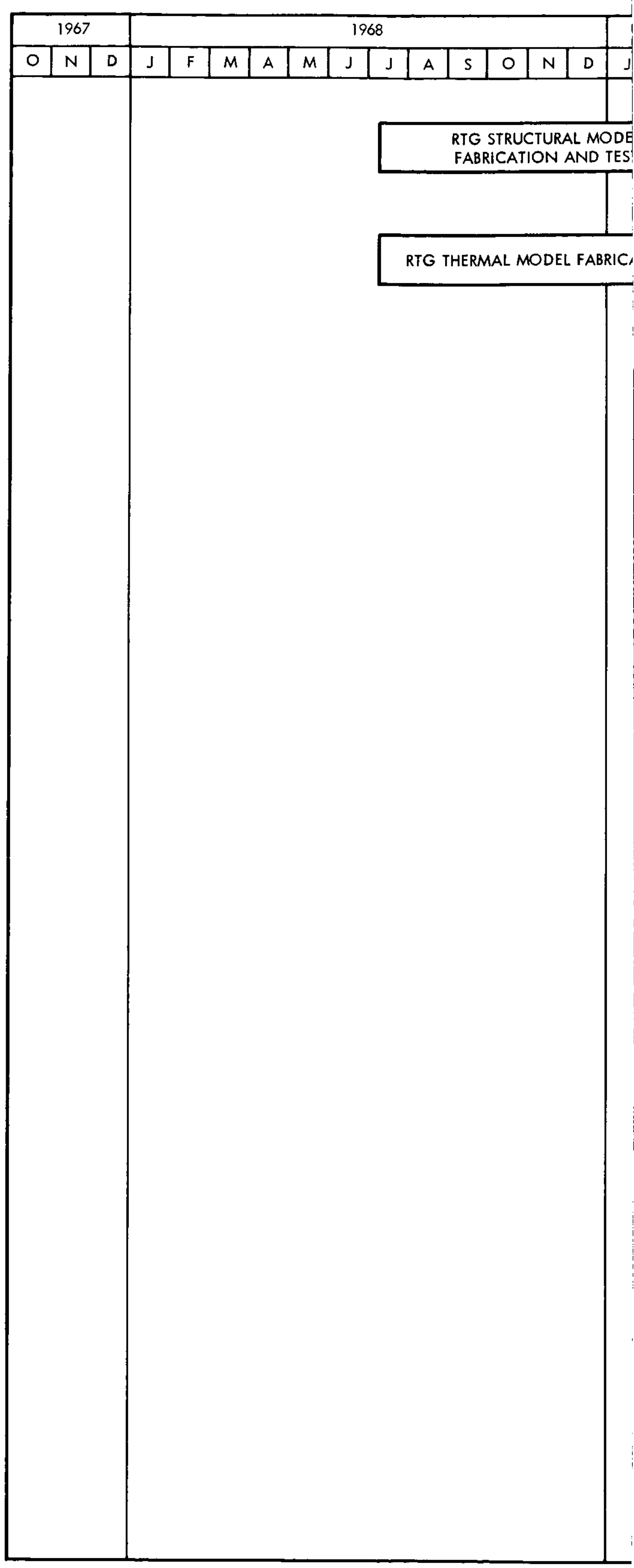


Figure 6. Capsule System Project Flow for Initial Mission (1 of 3)(Capsule Project)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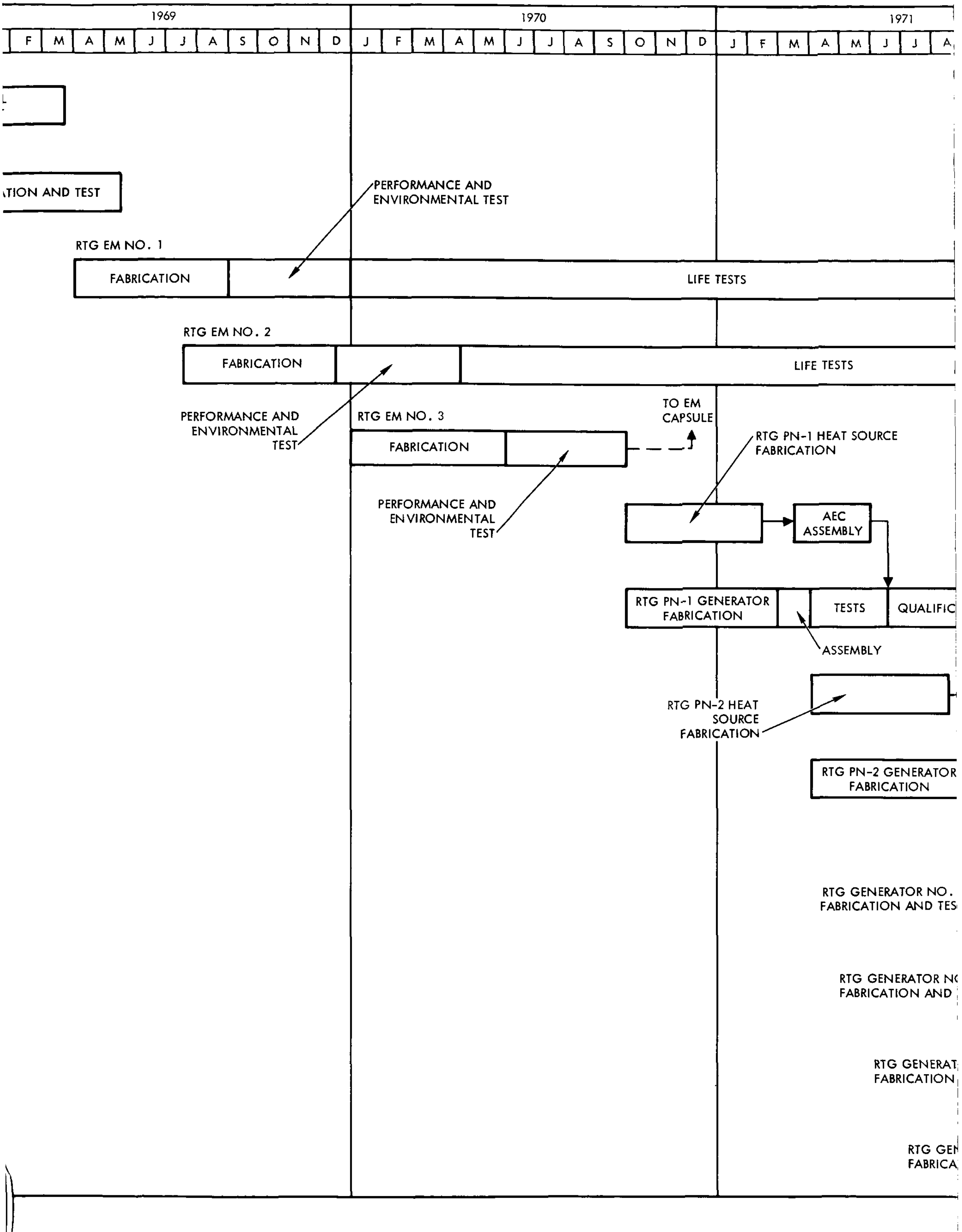
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PERFORMANCE AND ENVIRONMENTAL TEST
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AEC ASSEMBLY
RTG PN-1 GENERATOR FABRICATION
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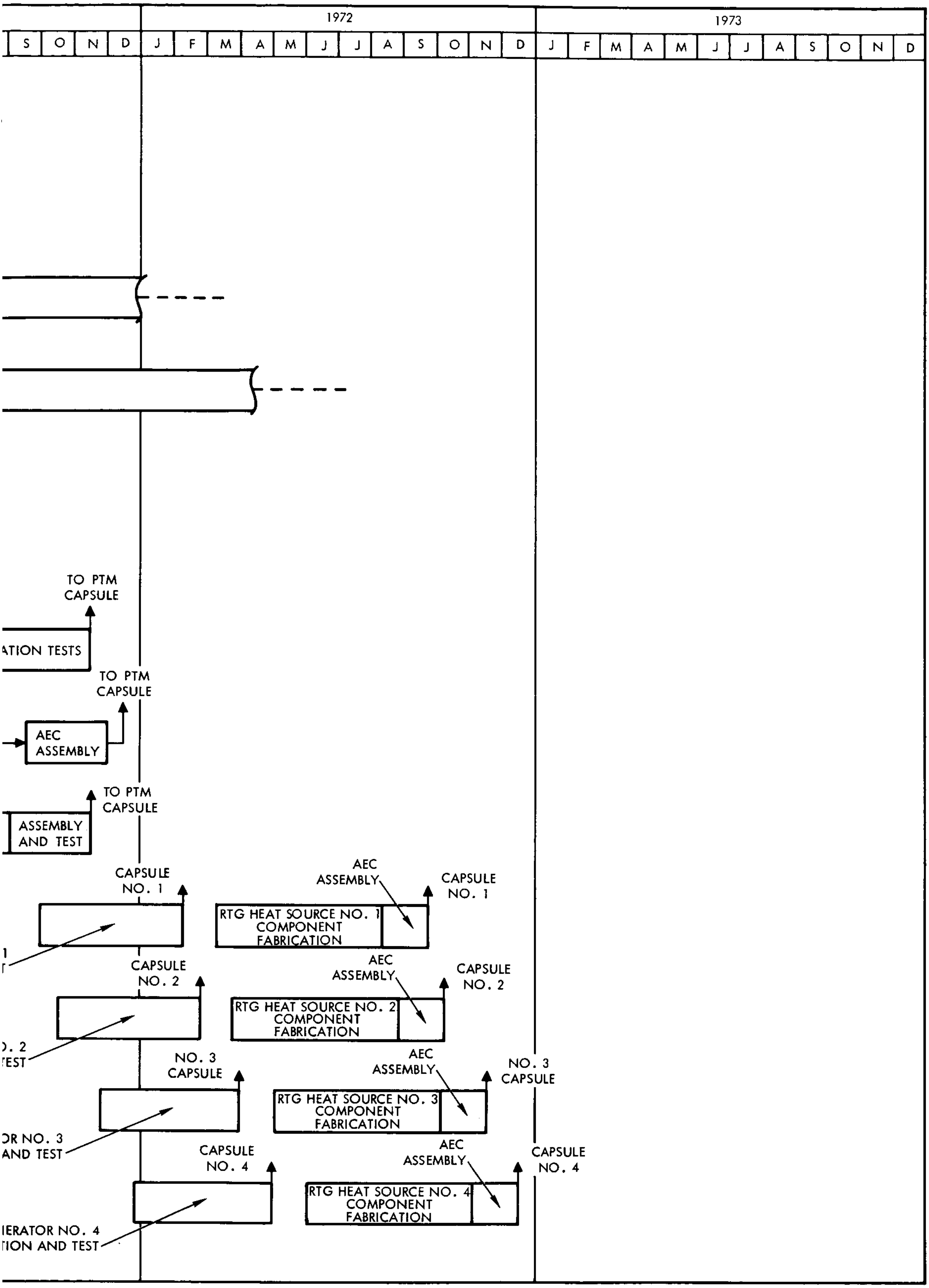
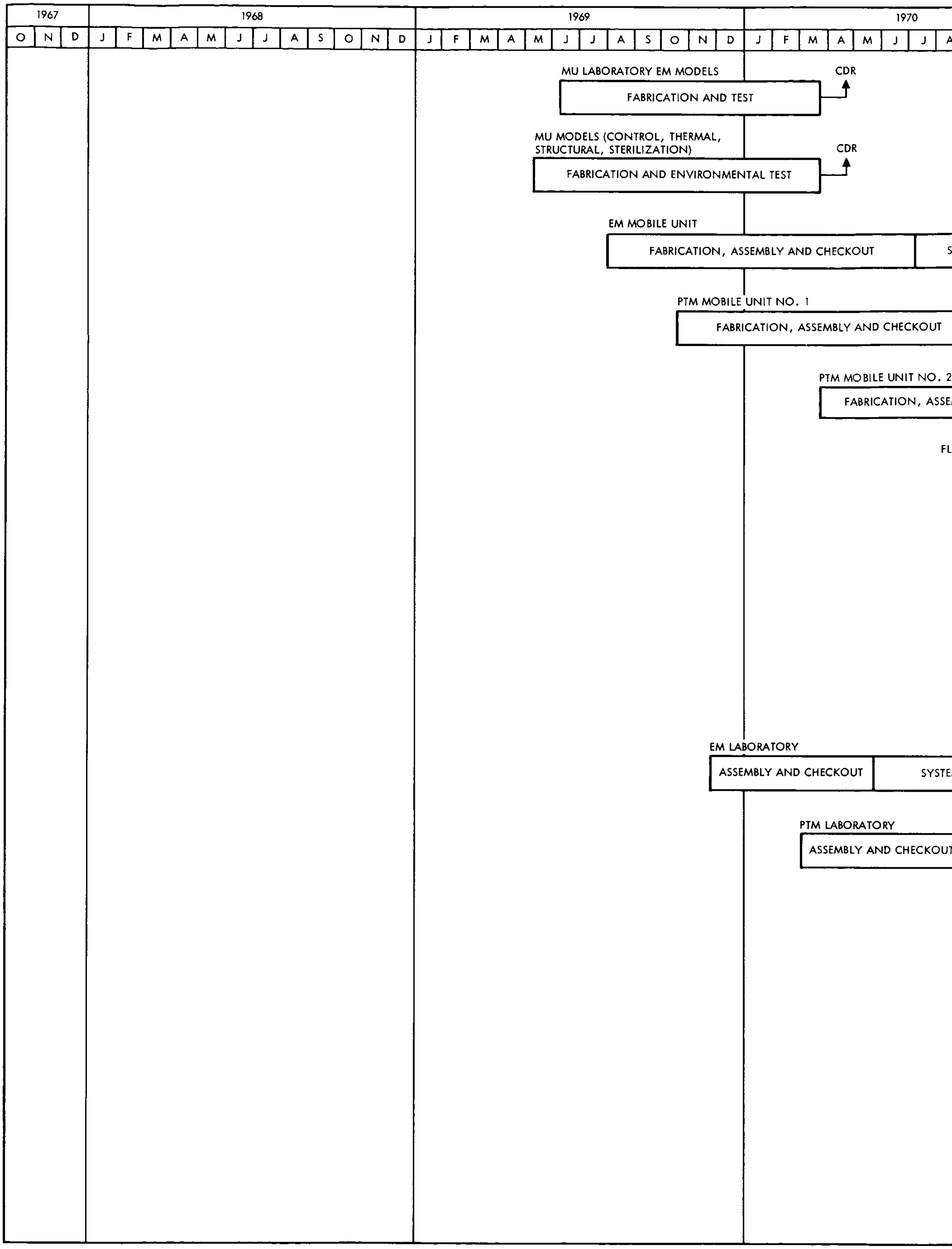


Figure 6. Capsule System Project Flow for Initial Mission (Continued)(2 of 3) (RTG Project)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FABRICATION AND ENVIRONMENTAL TEST
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EM MOBILE UNIT
FABRICATION, ASSEMBLY AND CHECKOUT
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FABRICATION, ASSEMBLY AND CHECKOUT
EM LABORATORY
ASSEMBLY AND CHECKOUT
PTM LABORATORY

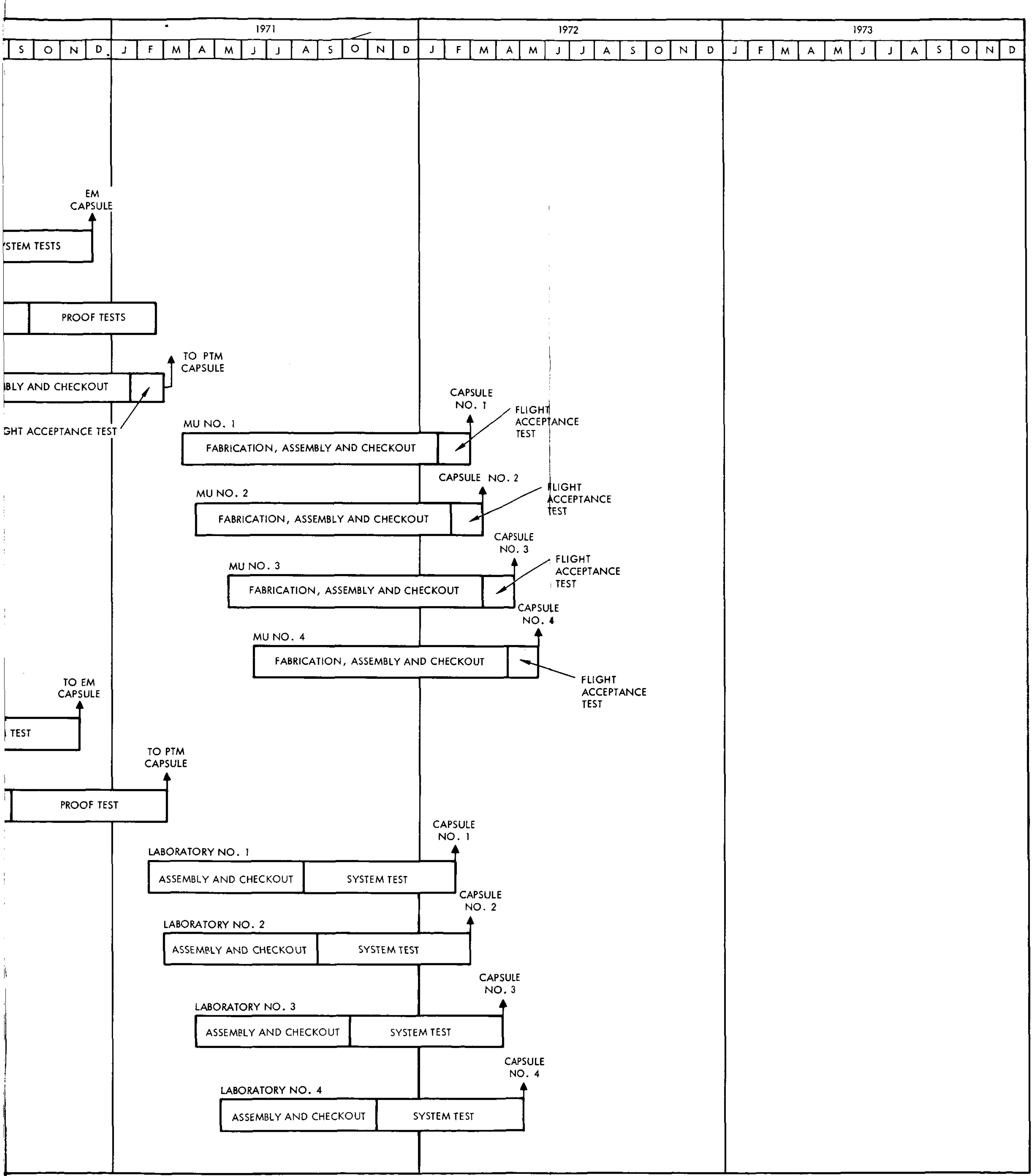


Figure 6. Capsule System Project Flow for Initial Mission (Continued)(3 of 3) (Landed Science)

- Thermal model (TM)
- Engineering model (EM)
- Propulsion integration model (PIM)
- Proof test model (PTM)

These capsule models are used primarily for design verification testing. The SM and PIM, however, are also used for initial subsystem qualification testing and the PTM is used to complete subsystem qualification, perform systems level qualification, and verify capsule flight acceptance test procedures.

The configuration model is initially constructed as a soft article and is later upgraded to a hard configuration. This mockup is used as an engineering tool early in the program. The hard mockup will be maintained correspondent with design until the completion of the first deliverable capsule. The principal functions are as follows:

- Develop internal and external flight configuration
- Develop routing of plumbing and harnessing
- Represent spacecraft-capsule interfaces and interfaces with the surface laboratory and mobile unit and the RTG
- Develop OSE interfaces

The SCM simulates a full-size capsule configuration and is capable of enduring repetitive exposures to the ETO/heat-sterilization cycle. It consists of a representative metallic structure with dummy subsystems. At the contractor's facility this model is used primarily in support of the capsule clean-room and sterilization-facility operations. The principal functions of the SCM are as follows:

- Train personnel involved in operations within the Class 100 facility
- Develop factory procedures in contamination-controlled areas
- Verify clean-room facility procedures. Completion of this activity relieves the constraint upon the start of the PTM structure final assembly by demonstrating the validity of capsule factory buildup

- Conduct contamination control investigation and verification tests. Completion of this phase relieves the constraint upon the start of PTM testing by demonstrating validity of contamination control techniques

This model would also be made available to KSC for terminal sterilization facility verification tests and capsule contamination control procedures verification.

After assembly and integration of the capsule bus with the surface laboratory, mobile unit, and RTG, checkout of the entire capsule system will take place at the capsule contractor's facility.

Upon completion of decontamination operations, acceptance tests, and mission acceptance review, four overall capsule systems will be shipped to KSC from November 1972 to January 1973 allowing about eight months for prelaunch checkout, sterilization operations, planetary vehicle integration support at KSC, and pad operations.

During follow-on missions the capsule bus like the spacecraft will remain fairly standardized in its configuration. However, extensive changes to the surface laboratory and mobile unit for the second and third generation missions will impose considerable implementation activities upon the capsule contractor. Thus slightly more than two years has been scheduled for implementation of the capsule systems for these future missions.

5.3 IMPLEMENTATION ALTERNATIVES

Many of the project alternatives discussed in Section 4. 3 that deal with general implementation considerations apply as well to the capsule project. Here only those alternatives peculiar to the capsule project are discussed.

5.3.1 Capsule Performance

The most significant capsule implementation alternatives relate to the level and phasing of capsule landed payload and science support performance, i.e., the capability to be accommodated versus any concomitant implementation complexity. However, an increase in gross landed payload capability does not necessarily result in additional developmental complexity. Rather, if this capability allows a more conservative, straightforward design approach, the net result is to simplify the program and yield a higher schedule confidence.

The major question then relates to the degree of science support provided by the capsule both initially and downstream. Here the tradeoff is fundamental and involves the degree of exploration selected as a basic program goal versus the required program scope and cost. As presented in Reference 1, the postulated approach is a comprehensive Mars exploration program. In that framework it has been argued that a significant precursor life detection capability is required on the first mission. The associated lifetime requirement, coupled with the desired ultimate long-stay capability, leads to early implementation of an RTG power source. A significant objective of the study was to examine the feasibility of such an RTG implementation. The conclusion from this preliminary investigation was positive and it is felt that such an implementation can be carried out for the 1973 mission with high confidence of success if pursued vigorously.

Another significant performance aspect affecting capsule implementation is the need for high data rate. This is a key feature for the postulated comprehensive Mars exploration capability. The resulting capsule configuration affects the system breakdown and associated implementation responsibilities as discussed below. It also has a strong impact on mission operations and associated support.

5.3.2 Capsule System Breakdown

The capsule system breakdown for the reference approach corresponds to the ground rule at initiation of the study. It differs from current Voyager plans in that a single system management office is considered instead of separate offices for the capsule project and for the landed science. The tradeoff here relates to a more uniform work load distribution among NASA centers versus the added complexity of an additional intersystem interface. The only aspect considered here is that of interface definition.

The reference science support includes a large high-gain antenna and medium-gain backup with RTG power and associated semi-passive thermal control. With this equipment there will be significant associated vehicle design and integration aspects. Hence the science support equipment is consolidated with the capsule bus project segment to be implemented by the capsule contractor, rather than as part of the surface laboratory project.

5.3.3 Capsule Integration and Delivery

Various alternatives exist for the degree of participation of the contractors for the surface laboratory, mobile unit, and RTG equipment in the capsule integration and delivery process. Because of the complexity of the associated interfaces it is felt desirable to have as complete a capsule system acceptance test as possible for acceptance prior to commitment of the hardware to the operations phase. This then requires separate acceptance tests of these elements at an earlier time consistent with delivery as GFE to the capsule contractor.

5.3.4 Contamination Control and Sterilization

The area of biological contamination control and sterilization for the capsule project is a complex one involving many alternatives that require treatment outside the limits of this study. However it is concluded that there is a requirement for a special capsule test article to support comprehensive contamination control development activities encompassing personnel training and procedure and facility verification.

Alternatives exist in regard to treatment of propellants and thermolabile components during heat sterilization. It appears possible to design tankage to be compatible with sterilization with on-board propellant, but detailed design studies are needed. The thermolabile elements associated with life detection experiments will probably require sterile insertion after the heat cycle.

6. RTG IMPLEMENTATION

6.1 ROLES AND RESPONSIBILITIES

The Voyager RTG is implemented by an associate contractor under the cognizance of the AEC as described in Section 5.1. After the RTG objectives are defined jointly by the AEC and NASA, the AEC will assume RTG development responsibility and NASA will assume RTG-vehicle integration responsibility. The RTG will be a government-furnished item to be integrated into the capsule by the capsule contractor under the technical direction of the capsule SMO. Close liaison between the two contractors and the NASA and AEC project offices concerned will be essential, since RTG and vehicle interactions give rise to a complex engineering job.

Although vehicle integration of the RTG will be carried out by the capsule contractor, the RTG contractor will provide extensive support. A particularly critical interface arises in rejecting RTG heat through the capsule canister and launch vehicle shroud. Other important interfaces involve countermeasures for the effects of RTG radiations and magnetic fields, and system checkout and handling procedures after nuclear heat source installation. An RTG-Voyager capsule interface working group with AEC, NASA, and contractor participants for resolving such interfaces is advisable.

The stockpiling, processing, shipment, and encapsulation of Pu 238 fuel in the form and quantities required will be an AEC responsibility. Fuel capsule design, development, qualification, and component fabrication will be an RTG contractor task. Components other than fuel will be shipped by the RTG contractor to an appropriate AEC facility, such as Mound Laboratory, for fuel capsule loading and closure and heat source assembly. Shipping containers which dissipate the heat source power and reduce its radiation will also be provided by the RTG contractor.

Safety documentation necessary to obtain approvals for operations involving nuclear heat sources will be generated by the RTG contractor, with Voyager vehicle, trajectory, environmental, and mission inputs furnished as required. These documents will include safety analyses for normal and all conceivable abort circumstances, presented in accordance with AEC-established format. They will also include substantiating experimental evidence and test results from the heat source development program. Preliminary, interim, and final safety reports will be processed through AEC, NASA, and DOD (range operation) channels. The earlier reports will form the basis for approving nuclear ground test operations in RTG contractor and Voyager capsule contractor facilities.

6.2 IMPLEMENTATION APPROACH AND SCHEDULE

The gross RTG project flow for all missions is shown in Figure 4 and is in more detail for the initial mission in Figure 6. It has been assumed that the RTG system requirements will have been defined by the capsule contractor during Phase B. These requirements will be provided to the capsule SMO for review and transmitted to the AEC as the cognizant agency for implementation of this system. A contract award by the AEC is estimated to occur by April 1968. To permit timely integration of the RTG system into the capsule system, delivery of eight RTG systems (with simulated heat sources) has been scheduled for the first half of 1972. The radioisotope heat sources will also be shipped to the capsule contractor facility during the last quarter of 1972. The heat source is used only for final capsule acceptance testing to minimize the hazards associated with isotope handling. It is felt that with radiation signature data supplied to the capsule contractor, integration and checkout of the capsule using the RTG system with the simulated heat source will prove adequate for much of capsule system testing. Eight heat sources are to be supplied for each mission. This approach will be compatible with supplying two spare flight capsules in a complete flight-ready condition. The RTG systems for the follow-on missions will be implemented on the basis of a two-year cycle, but with each cycle starting approximately six months prior to the launch date of the previous mission. Furthermore, to conserve the isotope inventory, it is anticipated that unused spare heat sources will be sent back to the AEC for reprocessing and used again on future missions.

After extensive testing of heat source materials and components and of RTG engineering models operated with simulated heat sources, two prototype RTG's complete with nuclear heat sources are programmed. The first prototype is used for qualification tests conducted by the RTG contractor and then shipped to the capsule contractor's facility. A second prototype is also shipped to the capsule contractor, but only the generator is processed through the RTG contractor's facility while the assembled heat source is shipped directly from Mound Laboratory. Both prototypes are then installed in the capsule proof test model for qualification testing of the entire capsule system in its nearly exact flight configuration. Thereafter, the prototypes are available for KSC facility checkout.

All generators are checked before and after vehicle installation using electrical heat source simulators. Flight generators are fabricated in advance of their nuclear heat sources, acceptance-tested by the RTG contractor, and shipped to the capsule contractor facility. There they are installed in the capsule and heated electrically during capsule checkout and acceptance tests. They remain in the capsule when shipped to the launch site and during all subsequent movements and testing. Nuclear heat sources are assembled at Mound Laboratories and shipped to the capsule contractor's facilities for inclusion in final acceptance testing. They are then shipped separately to KSC and installed in the generators just prior to canister sealing and sterilization.

Three non-nuclear RTG engineering models are fabricated and subjected to performance and environmental tests by the RTG contractor. Two of these units are retained for life testing while the third is shipped to the capsule contractor for use with test configurations of the capsule system.

6.3 IMPLEMENTATION ALTERNATIVES

6.3.1 Feasibility for 1973 Mission

The basic implementation alternative regarding RTG power for Voyager is whether to incorporate it in the 1973 mission or to wait until the 1975 launch. As discussed in Reference 1 and Section 5.3.1, incorporation of RTG power in the initial mission is desirable if feasible. The basic question of feasibility hinges more on administrative than technical factors. That is, if project requirements and inter-agency arrangements can be settled expeditiously to allow preliminary design to be completed in 1968, then the detailed design, development, fabrication, and delivery could be accomplished by the RTG contractor in support of the capsule project as shown in Figure 6.

6.3.2 RTG Configuration

The reference RTG approach utilizes a planar configuration (heat rejection in one direction) located within the capsule. This has significant implications regarding capsule integration and operations. Thus, if thermal control, radiation damage, or operational problems arising from this approach should become evident during detailed system design, other configurations such as non-planar RTG designs can be considered. Planar RTG configurations provide design flexibility inasmuch as they can be integrated either directly into the capsule equipment compartment or mounted externally. They can be positioned so that a portion of the rejected heat is effectively utilized in the capsule thermal control system. In addition, the planar heat rejection normally results in a simple, efficient radiator design and heat source-thermoelectric converter configuration. However, an effective insulation and structural support system must be utilized to avoid heat losses in all but one direction, and the insulation must function at the highest (least efficient) temperature.

Non-planar RTG's of interest for theVoyager capsule include the finned cylinder and a modification of the planar configuration with thermoelectrics on both sides of a flat plate heat source. In the finned cylinder, a cylindrical isotope source transfers heat radially to a surrounding thermoelectric converter. Thermal insulation at the ends of the generator prevents excessive heat losses. When the converters are placed on both sides of a flat-plate heat block, the insulation and structural requirements are much less severe than for the planar configuration, and the system is thermodynamically more efficient. Since the heat flux from the heat source is lower than for an equivalent planar RTG, the isotope capsule temperature is lowered, with an accompanying reduction in weight. However, the RTG must be positioned to reject heat in both directions along a single axis without excessive heat transfer to thermally sensitive components.

The radiological safety requirement for fuel containment in all possible abort situations, particularly aborts leading to earth re-entry and impact, is the most demanding RTG design constraint and has led to the recommendation that a high-temperature heat source be developed using refractory alloy structures, noble metal alloy claddings, and graphitic re-entry sheaths. Although required primarily to achieve inherent, passive re-entry survival capability, such a heat source can be operated continuously at high enough temperatures (2000°F) that its use with a Si Ge thermoelectric converter is advantageous. An RTG of this description represents an advanced development but one which is considered highly desirable because of marginal safety capabilities of the lower temperature superalloy-Pb Te RTG systems which have received primary developmental attention to date.

6.3.3 Nuclear Radiation Considerations

Use of the RTG as the flight capsule power source requires judgements to be made throughout the program as to the heat source requirements, whether it be the radioisotope or a simulator incorporating a non-nuclear thermal source. The use of the nuclear source requires AEC controls and certifications for safety considerations which adds to program complexity and should be minimized consistent with technical requirements.

The first use of the radioisotope is planned for the PTM Electromagnetic Interference tests at the capsule contractor's facility. As an alternate proposal, it would be reasonable to consider locating these tests at an AEC facility such as Mound Laboratory. In this event a capsule system model simulating the electronics systems would be required.

The use of a nuclear source during capsule acceptance as for the reference approach may well be eliminated when the comparison between this complexity and the adequacy of a simulated source is considered in detail.

7. SURFACE LABORATORY IMPLEMENTATION

7.1 ROLES AND RESPONSIBILITIES

The three-generation surface laboratory implementation will be carried out by the surface laboratory contractor as described in Section 5.1. The surface laboratory contractor has two principal functions, that of integrating experiment packages into a total laboratory and providing the structure, mechanisms, and electronic equipment to support the experiments. He must accomplish these functions for successively more complex laboratories, and implementation must be such that the overlapping of the requirements to begin development of the comprehensive precursor laboratory does not interfere with operations for the first-generation mission.

The science definition program for the surface laboratory will be managed by the NASA Voyager Project Office, with direct management of the principal investigators by the capsule system management office. During preliminary design the system approach for the science program is developed in detail. Operating procedures are established in detail to ensure maintaining the scientific integrity of the experiment program, to direct participation and control by the principal investigators, to define acceptable interface arrangements for all participants, and to provide for adequate decision-making machinery during system development and Mars surface operations. These operating procedures and the definition of the nominal surface laboratory define the instrument complement, sampling, and processing capability, data processing and analysis capability, and generic description of science and experiment types contemplated. Potential principal investigators would respond to RFP's for the proposed experiments planned to utilize the specified laboratory capability.

An initial selection of principal investigators would be made and the selected investigators would then participate in the final science definition. During this period the group of selected experiments would be further defined to maximize the combined information content and to optimize the surface laboratory configuration. Concurrently, the principal investigators would develop the specific experimental techniques so that the step-by-step experimental procedures are available. This information establishes the requirements for the corresponding parts of the laboratory and defines the operating requirements for the related subsystems.

The principal investigators continue on the program, coordinating continuously with the surface laboratory contractor as the hardware is developed and tested. They participate in development of operating procedures for Mars operations. During the operating life on Mars, they analyze the appropriate scientific data and participate in control of experiment operation.

Under the foregoing guidelines, the principal investigators will have responsibility for the development of the experimental methods for the particular experiments and the design, development, and fabrication of instrumentation required to perform the experiments as appropriate. The surface laboratory contractor will have the responsibility for all mechanisms required for sample acquisition and deployment as well as those mechanisms to support experiment packages.

The implementation of the experiments involves both intersystem and subsystem considerations. The relation between the laboratory contractor and the principal investigators is analogous to an intersystem interface in that the principal investigators have independent contracts with NASA. At the same time, the experiment equipment as well as other science elements have a complex and intimate relationship to the other hardware akin to that of a laboratory hardware subsystem, a fact which requires a comprehensive role on the part of the laboratory contractor for integration of such equipment. As a corollary, such major support elements as the equipment for sample acquisition and preparation and the data automation equipment should be developed by the laboratory contractor. Hence the science integration role of the surface laboratory contractor is similar to that of the spacecraft contractor as discussed in Section 4.3.4.

7.2 IMPLEMENTATION APPROACH AND SCHEDULE

The gross surface laboratory project flow for all missions was shown in Figure 4 and in more detail for the initial mission in Figure 6. Since it has been assumed that Phase B activities for this system will be the responsibility of the capsule contractor, implementation of this system by the surface laboratory contractor will commence with Phase C. The RFP for this phase should be issued by January 1968 and a contract award made about April 1968 if the overall schedule of Figure 4 is to be accommodated.

While Phase C and D activities, in general, will be similar to spacecraft and capsule bus implementation, interface control will become a significant effort because of the numerous interfaces between the surface laboratory, mobile unit, capsule bus, RTG, and the related electromagnetic compatibility as well as compatibility with the decontamination and sterilization cycles must be demonstrated. Therefore, three years have been allowed for the Phase D implementation of this system for the first mission. Shipment of four surface laboratory systems to the capsule contractor in mid-1972 appears achievable. Second and third generation surface laboratory systems will be considerably more complex. To meet the 1977 launch date, Phase C activities will be initiated by August 1972 and Phase D by April 1973. This will permit approximately four years for development of the comprehensive surface laboratory configuration.

Since the scientific instruments are likely to be the longest lead-time components, it is important that their development start as soon as feasible. It is planned that the initial development would be of a breadboard nature, during which the fundamental techniques would be established and sterilization compatibility determined. During this time, functional changes can be accepted with minor impact, as long as basic operating principles are not modified. The prototype designs would be based on specific performance requirements, and would be fabricated of components that are (short term) qualified for sterilization, shock, and other environments.

In addition to the same type of development tests planned for the capsule bus, the engineering model of the surface laboratory will also be used for extensive mission simulation tests. This will consist of operation of the surface laboratory model in a chamber approximately duplicating the 10 mb, CO_2 atmosphere (with the atmosphere model revised as more recent data is available) and the thermal cycling anticipated at the projected landing site.

The surface laboratory contractor will provide support to the capsule contractor during the integration and intersystem testing activities conducted both at the capsule contractor facility and at KSC. This support activity could extend well over a year and hence it has been assumed that the surface laboratory contractor will provide permanent teams of personnel at both the capsule contractor's facility and at KSC, in order to meet the schedules indicated.

7.3 IMPLEMENTATION ALTERNATIVES

Many capsule and spacecraft project alternatives discussed in Sections 4.3 and 5.3 apply as well to the surface laboratory project. As with the capsule, the most significant surface laboratory alternatives relate to the exploration capability to be provided versus the associated implementation complexity. The general tradeoff has been made within the framework of the postulated approach to arrive at the reference stepwise development. Detailed surface laboratory design studies coupled with implementation investigations are still required to arrive at a specific compromise between simplification of the first generation instrumentation and the required precursor life detection capability.

8. MOBILE UNIT IMPLEMENTATION

Implementation of a Voyager mobile unit is discussed in this section in keeping with ground rules of the current study. Within the resources of the study it has not been possible to carry out a preliminary design and develop a related implementation definition for such a unit. However, a cooperative data exchange between TRW and the AC Defense Laboratories of the General Motors Corporation was arranged to make available data from the extensive work of General Motors in this area. This information has served as the basis for the material presented below.

The mobile unit, as a major element of the capsule system, is implemented by the mobile unit contractor under the direction and management of the capsule system management office. This contractor functions as an associate contractor with the capsule contractor and the surface laboratory contractor as described in Section 5.1.

8.1 IMPLEMENTATION APPROACH AND SCHEDULE

The gross mobile unit project flow for all missions was shown in Figure 4 and in more detail for the initial mission in Figure 6. Because the mobile unit has important interfaces with the surface laboratory and the capsule bus, extensive interface control documentation will have to be generated early in the program. As in the case of the surface laboratory, the Phase B implementation of the mobile unit will be conducted by the capsule contractor.

Mobile unit implementation will be initiated with the issuance of a Phase C RFP in January 1968. Contract award is assumed to take place in April 1968, and the preliminary design review completed by November 1968. One unique aspect of mobile unit implementation will be that the initial test vehicle will be designed to be compatible with the anticipated weights and volumes for the experiment packages to be used on the advanced mobile unit. In this way the reliability of the advanced mobile unit structure and drive mechanism can be enhanced by drawing upon the initial operational experiences of the earlier mobile units. The design compatibility is also essential from a schedule point of view since a minimum of three years is normally required to develop and quality a mobile unit system.

Phase D for this system will be initiated in January 1969 to assure availability of four qualified units at the capsule contractor's facility by the first half of 1972. Again because of the numerous interfaces and inter-system test requirements, it will be essential that the mobile unit contractor maintain permanent support personnel at the surface laboratory contractor, the capsule contractor, and KSC during the assembly, integration, test, and decontamination-sterilization phases.

It has been assumed that the mobile unit contractor will have decontaminated his system prior to shipment to the capsule contractor. Hence, from that point on, the mobile units will have to be maintained under Class 100 contamination control. This will have a significant impact on the schedule from that point on since handling procedures become much more complex after this point is reached in the development phase.

Phase C for the second-generation mobile unit will be initiated in mid-1972. The associated Phase D will be started immediately thereafter, with the critical design review in mid-1974.

The second-generation mobile unit will be designed to meet both the second and third generation mission objectives. However, because of the time span involved, the delay of data received from the earlier missions, and the normal technological evolution that will occur over a 10-year period, some updating, improvements, and modifications will undoubtedly be applied to the basic mobile unit, as well as its payload, although these changes will probably not be of a major nature.

As shown in Figure 4, data from the first mission will not be available until early 1974. This is about 15 months prior to qualification and 27 months prior to delivery of the second generation mobile unit for the 1977 mission. The early design and development will thus have to proceed without this data, and the project will then have to react expeditiously as discussed in Section 3.

8.2 IMPLEMENTATION ALTERNATIVES

Many capsule and spacecraft project alternatives discussed in Sections 4.3 and 5.3 apply as well to the mobile unit project. Again the fundamental alternatives relate to exploration capability versus the associated implementation complexity. This is exemplified in regard to the inclusion of a test mobile unit for the initial mission, which obviously complicates implementation for the initial mission. However, the inclusion is felt to be justified in order to obtain test experience and a developmental base to support implementation of the advanced mobile unit, which is believed to be essential for the ultimate advanced mission exploratory capability.

The advanced mobile unit and the test mobile unit of the reference approach are both restricted to operation with line of sight to the lander. This enables communication with earth by relaying through the lander either by RF or wire link. Low power requirements for communications and low energy requirements per traverse for locomotion permit the use of rechargeable batteries on the mobile unit to supply all power and energy needs.

Operation beyond line of sight of the lander poses considerably more difficult problems, but offers concomitant scientific advantages. Neither RF nor wire link to the lander can be used, therefore requiring direct communication to earth from the mobile unit or relay through an orbiter, the latter being undesirable because of limited orbiter availability and added reliability problems. This leads to requirements for much greater power and a high-gain antenna which must be oriented each time data transmission is desired. Even with such measures it appears that data rates will be relative low.

Nevertheless, the scientific advantages of wide area coverage warrant serious consideration of this alternative. Operations conducted within a few hundred feet of the lander are quite likely to encounter fairly homogeneous conditions. The major advantage gained by mobility in this range is to get away from landing site contamination. Wide area coverage is considerably more likely to encounter variations in both terrain and physiochemical conditions. Once the autonomy is provided to go beyond line of sight, virtually unlimited range capability is conceivable. The inability to return regularly to the lander for battery recharge requires a prime energy source on the mobile unit (most likely RTG) for battery recharge, the batteries themselves being used only for peaking power.

Of course, all of this is costly both in terms of weight and mission time needed for antenna orientation or because of reduced data rates. The loss of time may be partly compensated by providing more control autonomy on the vehicle ranging from preprogrammed path plans, commands, and contingency strategies, to adaptive and learning systems embodying stochastic decision processes.

Such approaches can only be justified in terms of the tradeoff between the weight, cost, and complexity needed to supply the long range mobility versus the scientific gains to be realized by wide area coverage. One such mobile unit which has been considered has a gross weight of about 900 pounds. It carries 130 pounds of scientific instruments and has an overall length of approximately 12 feet.

9. LAUNCH VEHICLE IMPLEMENTATION

The launch vehicle system is implemented jointly by the Voyager shroud contractor and the various contractors for the standard Saturn V booster under the overall management of the launch vehicle system management office. Technical direction and contractual administration of these contractors is delegated to the MSFC Saturn V Project Office in support of the launch vehicle SMO.

9.1 SATURN V BOOSTER

The launch vehicle system for the Voyager program, excluding the shroud system, is assumed to be a standard "off-the-shelf" version of the Saturn V booster. There may be slight modifications required to the Saturn IVB and the instrument unit to make them compatible with the Voyager requirements, and flight dynamics studies will be required by the S-IC contractor. It has been assumed that by mid-1968, these will have been identified by the Phase C activities of the spacecraft and capsule contractors. At that time contract change notices would be issued to these contractors for implementating the required work. It has been assumed preliminary design will have been initiated by November 1968. A preliminary design review will be conducted in May 1969 and a critical design review in the first quarter of 1970, coincident with the CDR's for all the other major Voyager systems.

Following approval of these modifications by the Voyager project office and the launch vehicle SMO, fabrication of the S-IC, S-II, and S-IVB stages and the instrument unit would commence. There should be no difficulty for the launch vehicle project segments in meeting Voyager schedule requirements. The schedule calls for launch site compatibility testing in support of the first mission, followed by prelaunch operations. Subsequent missions will only require preparation for flight.

9.2 SHROUD IMPLEMENTATION

Implementation of the Voyager shrould as a new element of the launch vehicle system will be carried out by an associate contractor under the cognizance of the launch vehicle SMO. Assuming a Phase C RFP is issued in early 1968, it is estimated that a contract award would take place in April 1968. A PDR would be conducted by December 1968 in keeping with the other major Voyager system PDR activities. Phase D would commence at the start of 1969 and a CDR would be held by March 1970, to coincide with similar activities for the other major systems. Since the outside diameter of the cylindrical sections of the shroud system are identical to that of the S-IVB stage, it has been assumed that much of the tooling and fixtures developed for this stage can be used on this system. This factor has been taken into account in scheduling this new addition to the overall launch vehicle system.

The first flight-configured shroud system for the 1973 mission would be manufactured, checked out, acceptance tested, and shipped to KSC by mid-1972, or later as required. At KSC the complete shroud would be integrated with two flight planetary vehicles as part of launch site compatibility testing. An additional activity associated with the shroud system is checkout for compatibility with the Saturn V booster. The shroud contractor will provide support as required during launch site operations. Because the shroud system will become a standardized element of the launch vehicle system, no major schedule problems are anticipated for the implementation of additional systems for the future missions.

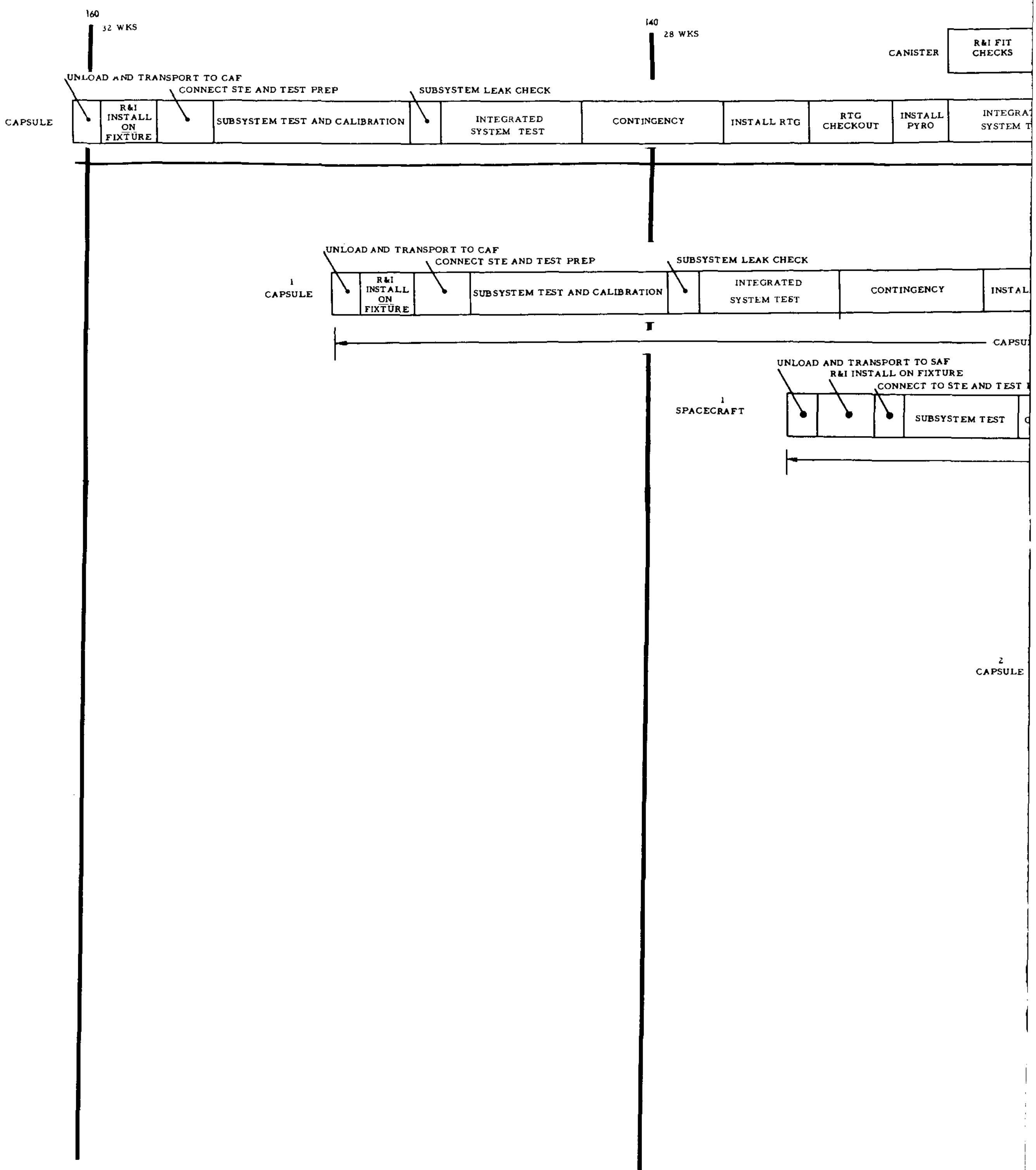
10. LAUNCH OPERATIONS

The launch operations system manager is responsible to the Voyager mission director for space vehicle prelaunch and countdown and for launch vehicle flight through injection into an earth parking orbit. In particular, he is responsible for launch readiness of the space vehicle, ground crews, and launch complex facilities and equipment as required to meet the critical Voyager launch window requirement. The manager carries out launch operations development activities as well as operational execution. He also coordinates with KSC to provide facilities and related support for spacecraft, flight capsule, and planetary vehicle prelaunch operations.

10.1 LAUNCH SITE ACTIVITIES

Voyager operational launch site activities commence with shipment of flight hardware to the launch site and end at the completion of space vehicle earth orbit injection. The operational flow, shown in Figure 7, includes shipment to Kennedy Space Center, receiving inspection, assembly and checkout, final prelaunch preparations, space vehicle integration, terminal countdown, launch, powered flight, and earth orbital injection. All facilities, personnel, and software for each Voyager mission must be in a mission support posture at the start of the operational phase. Each major system support element first demonstrates mission readiness and then participates in a total combined systems operations demonstration. These elements are exercised as a total system through a simulated Voyager mission.

After the spacecraft and capsules have completed prelaunch checkout in facilities provided for this purpose, they will be taken to the explosive safe area for assembly and checkout. The area will consist of a high bay area approximately 100 x 140 x 90 feet high incorporating a 40 x 70-foot air lock at one end. The high bay area also incorporates a special sealed chamber to conduct ETO decontamination of the planetary vehicle-shroud assembly.



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140
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CANISTER
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UNLOAD AND TRANSPORT TO CAF
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SUBSYSTEM TEST AND CALIBRATION
INTEGRATED SYSTEM TEST
CONTINGENCY
INSTALL RTG
RTG CHECKOUT
INSTALL PYRO
UNLOAD AND TRANSPORT TO CAF
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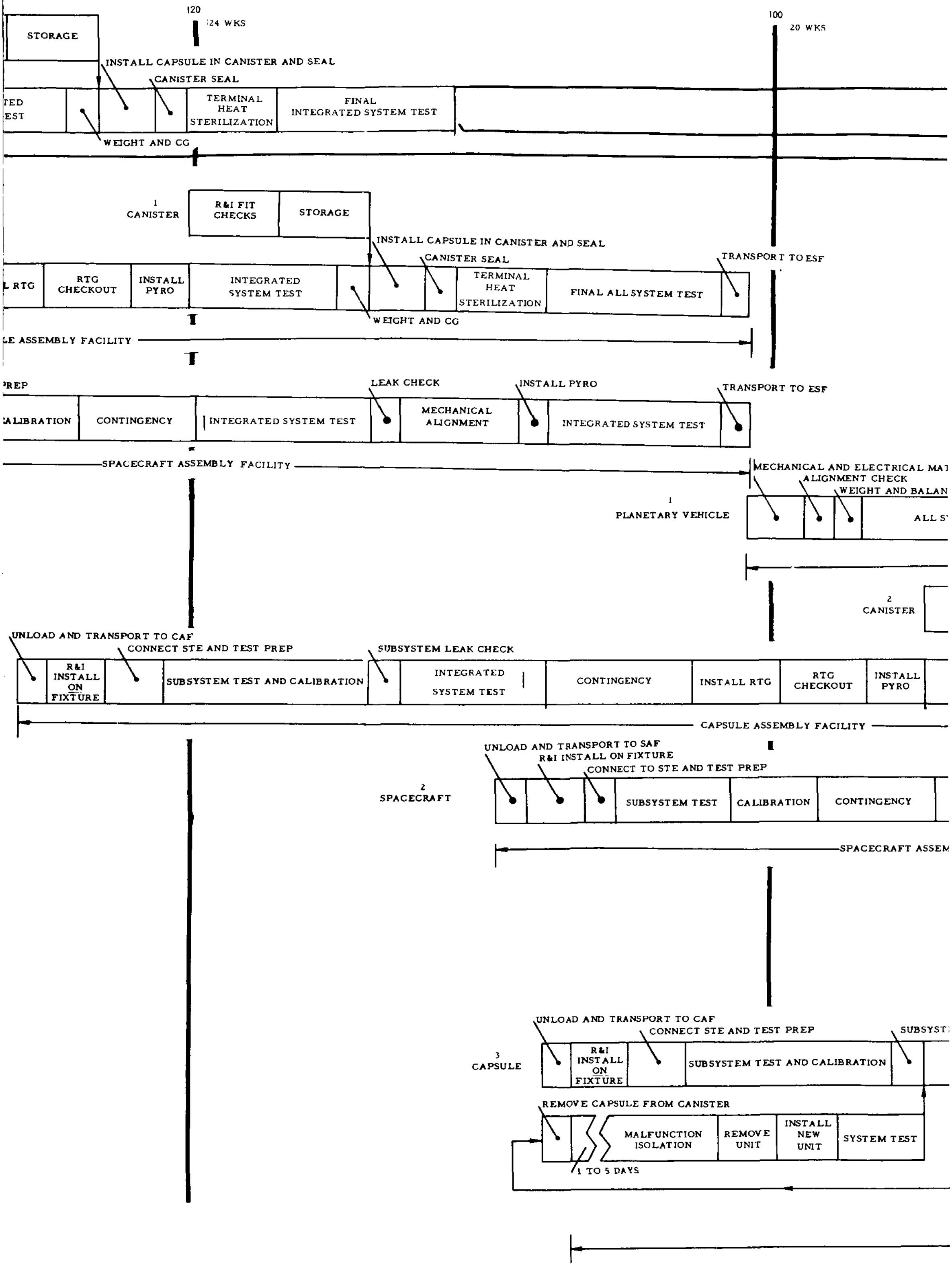
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STORAGE
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STORAGE
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CONTINGENCY
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MECHANICAL ALIGNMENT
INTEGRATED SYSTEM TEST
SPACECRAFT ASSEMBLY FACILITY
ALIGNMENT CHECK
1 PLANETARY VEHICLE
2 CANISTER
UNLOAD AND TRANSPORT TO CAF
CONNECT STE AND TEST PREP
SUBSYSTEM LEAK CHECK
R&I INSTALL ON FIXTURE
SUBSYSTEM TEST AND CALIBRATION
INTEGRATED SYSTEM TEST
CONTINGENCY
INSTALL RTG
RTG CHECKOUT
INSTALL PYRO
CAPSULE ASSEMBLY FACILITY
UNLOAD AND TRANSPORT TO SAF
R&I INSTALL ON FIXTURE
CONNECT TO STE AND TEST PREP
2 SPACECRAFT
SUBSYSTEM TEST
CALIBRATION
CONTINGENCY
UNLOAD AND TRANSPORT TO CAF
CONNECT STE AND TEST PREP
3 CAPSULE
R&I INSTALL ON FIXTURE
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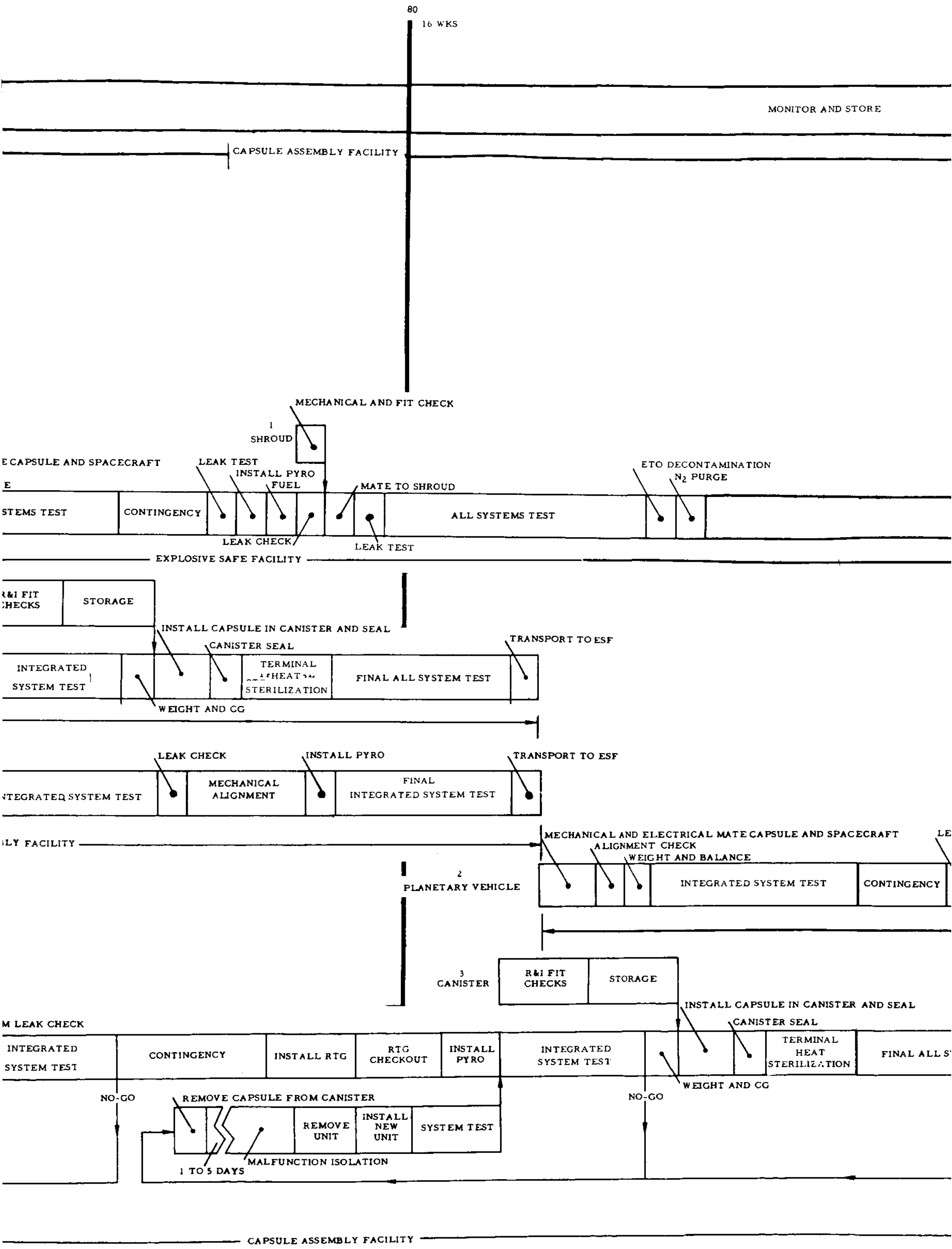
REMOVE CAPSULE FROM CANISTER
MALFUNCTION ISOLATION
REMOVE UNIT
INSTALL NEW UNIT
SYSTEM TEST
1 TO 5 DAYS

64-1



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MONITOR AND STORE
CAPSULE ASSEMBLY FACILITY
MECHANICAL AND FIT CHECK
1
SHROUD
E CAPSULE AND SPACECRAFT
LEAK TEST
INSTALL PYRO
FUEL
MATE TO SHROUD
ETO DECONTAMINATION
N_2 PURGE
STEMS TEST
CONTINGENCY
ALL SYSTEMS TEST
LEAK CHECK
LEAK TEST
EXPLOSIVE SAFE FACILITY
STORAGE
INSTALL CAPSULE IN CANISTER AND SEAL
CANISTER SEAL
TRANSPORT TO ESF
INTEGRATED SYSTEM TEST
TERMINAL HEAT STERILIZATION
FINAL ALL SYSTEM TEST
WEIGHT AND CG
LEAK CHECK
INSTALL PYRO
TRANSPORT TO ESF
MECHANICAL ALIGNMENT
FINAL INTEGRATED SYSTEM TEST
MECHANICAL AND ELECTRICAL MATE CAPSULE AND SPACECRAFT
ALIGNMENT CHECK
WEIGHT AND BALANCE
2
PLANETARY VEHICLE
INTEGRATED SYSTEM TEST
CONTINGENCY
3
CANISTER
R&I FIT CHECKS
STORAGE
INSTALL CAPSULE IN CANISTER AND SEAL
CANISTER SEAL
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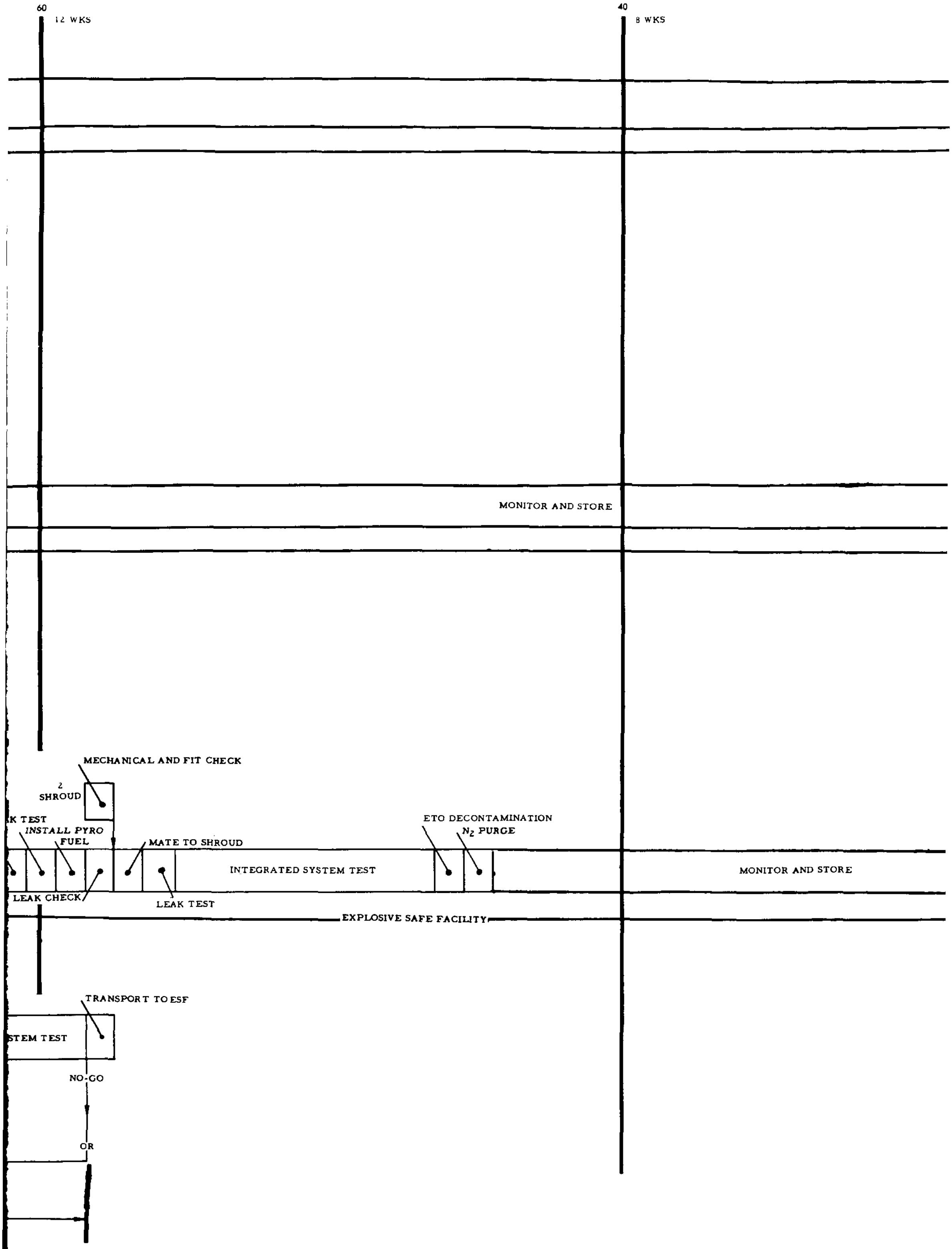
INTEGRATED SYSTEM TEST
CONTINGENCY
INSTALL RTG
RTG CHECKOUT
INSTALL PYRO
INTEGRATED SYSTEM TEST
TERMINAL HEAT STERILIZATION
WEIGHT AND CG
NO-GO
REMOVE CAPSULE FROM CANISTER
REMOVE UNIT
INSTALL NEW UNIT
SYSTEM TEST
NO-GO
1 TO 5 DAYS
MALFUNCTION ISOLATION
CAPSULE ASSEMBLY FACILITY

64-2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12 WKS
40
8 WKS
MONITOR AND STORE
MECHANICAL AND FIT CHECK
2
SHROUD
K TEST
INSTALL PYRO
FUEL
MATE TO SHROUD
ETO DECONTAMINATION
N_2 PURGE
INTEGRATED SYSTEM TEST
MONITOR AND STORE
LEAK CHECK
LEAK TEST
EXPLOSIVE SAFE FACILITY
TRANSPORT TO ESF
STEM TEST
NO-GO
OR

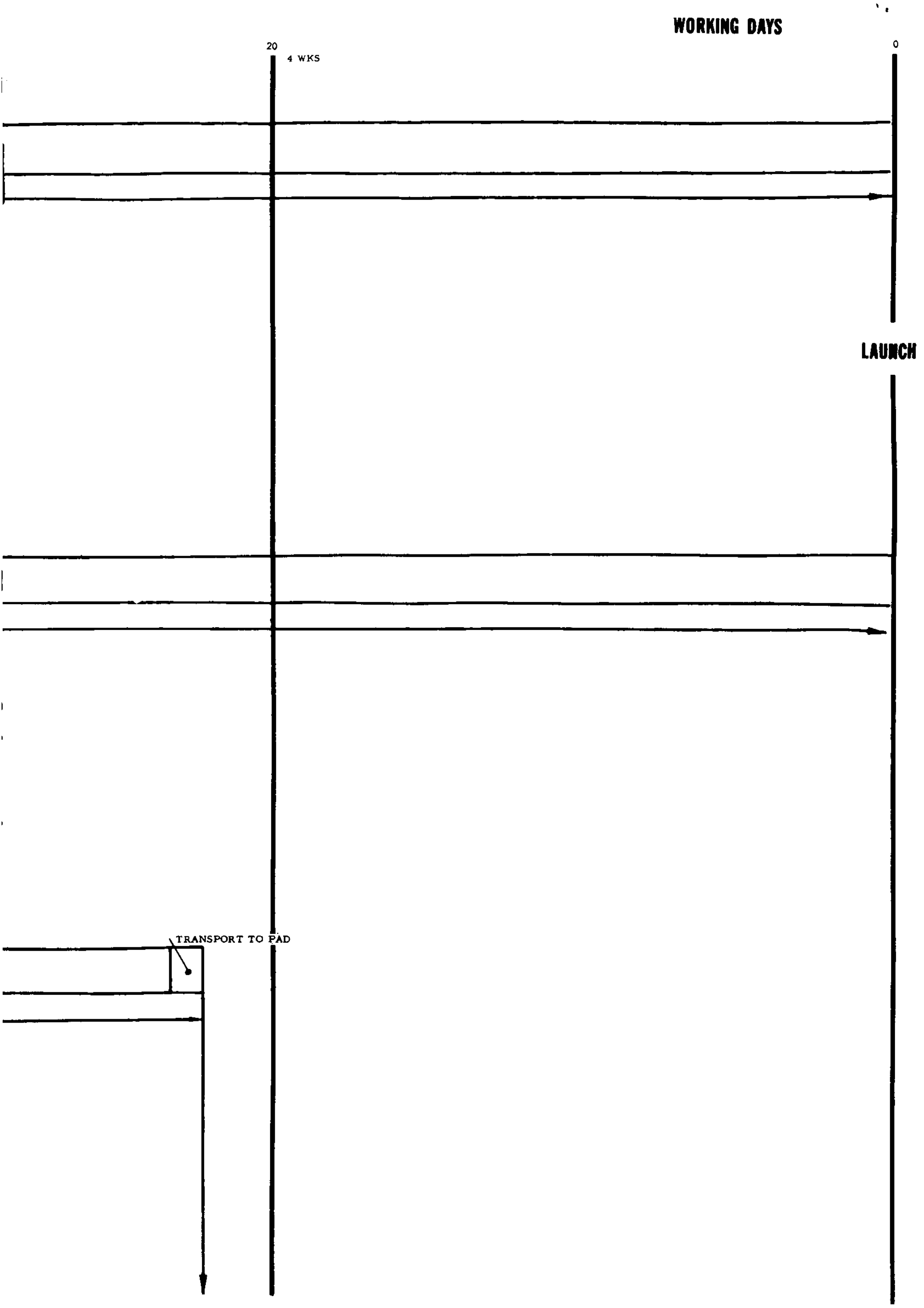
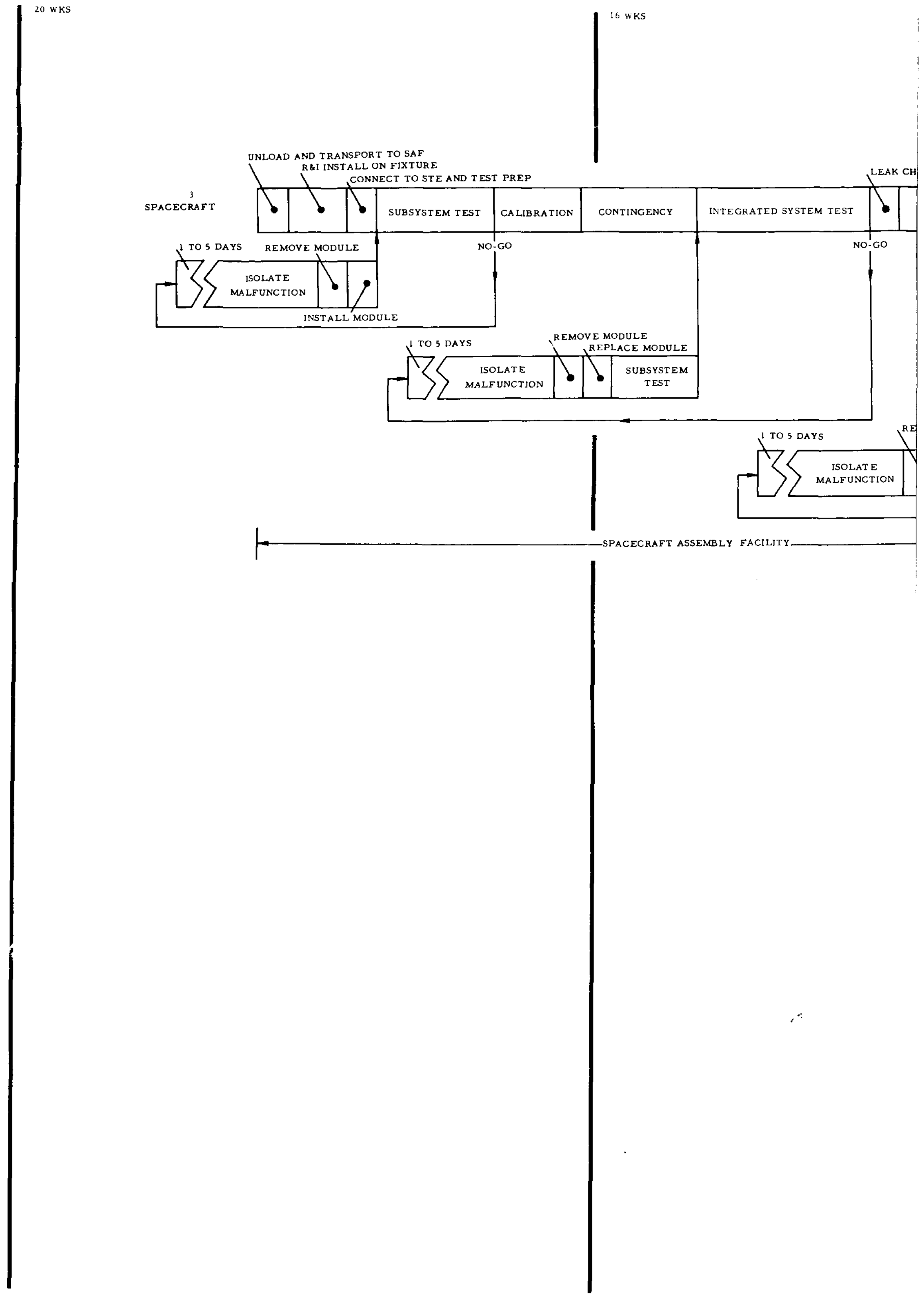
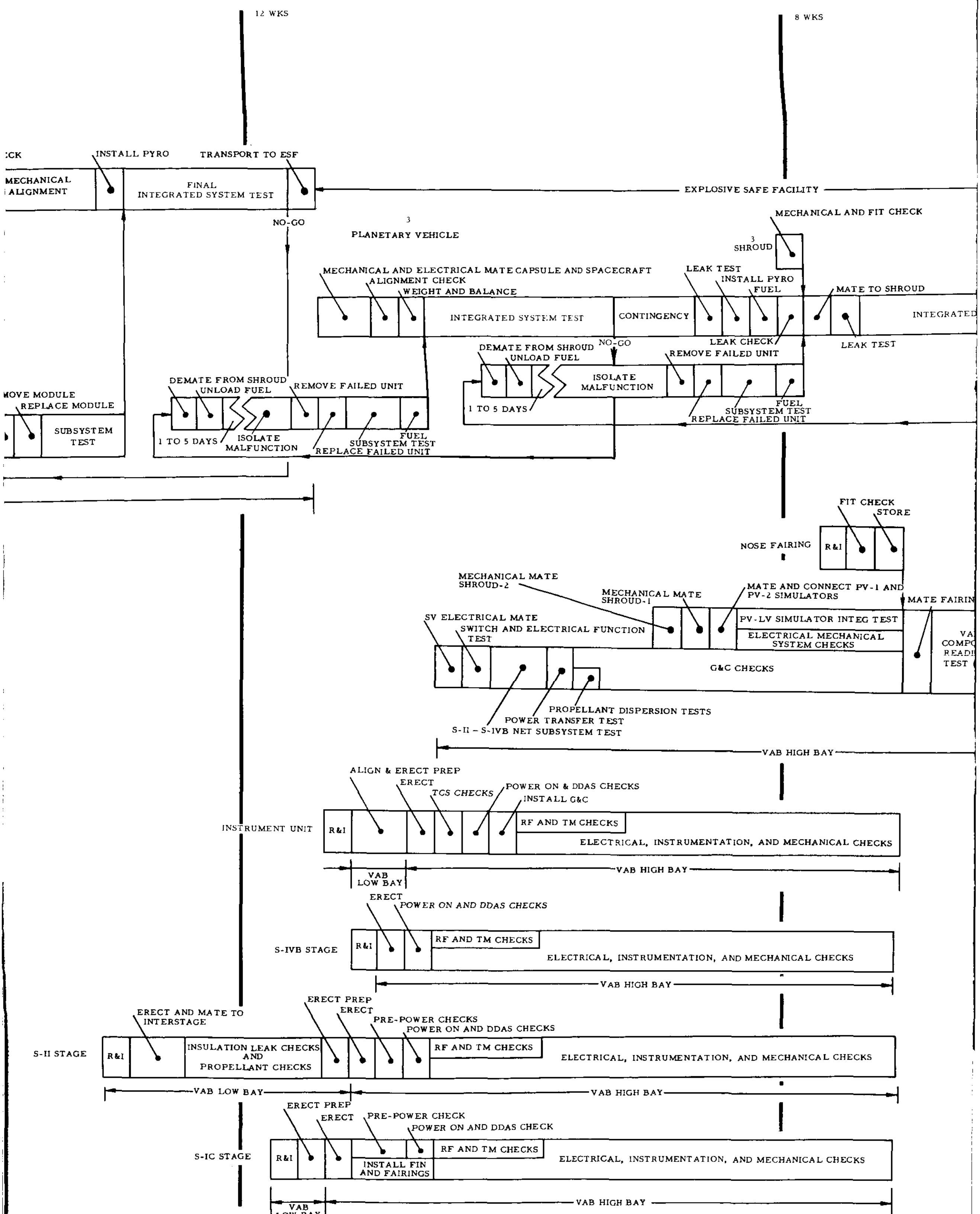


Figure 7. System Flow at Launch Site


20 WKS
16 WKS
UNLOAD AND TRANSPORT TO SAF
R&I INSTALL ON FIXTURE
CONNECT TO STE AND TEST PREP
3
SPACECRAFT
SUBSYSTEM TEST
CALIBRATION
CONTINGENCY
INTEGRATED SYSTEM TEST
LEAK CH
1 TO 5 DAYS
REMOVE MODULE
NO-GO
ISOLATE MALFUNCTION
INSTALL MODULE
1 TO 5 DAYS
REMOVE MODULE
REPLACE MODULE
ISOLATE MALFUNCTION
SUBSYSTEM TEST
NO-GO
1 TO 5 DAYS
RE
ISOLATE MALFUNCTION
SPACECRAFT ASSEMBLY FACILITY



12 WKS
8 WKS
CK
INSTALL PYRO
TRANSPORT TO ESF
MECHANICAL ALIGNMENT
FINAL INTEGRATED SYSTEM TEST
EXPLOSIVE SAFE FACILITY
NO-GO
3 PLANETARY VEHICLE
MECHANICAL AND FIT CHECK
3 SHROUD
MECHANICAL AND ELECTRICAL MATE CAPSULE AND SPACECRAFT
ALIGNMENT CHECK
WEIGHT AND BALANCE
INTEGRATED SYSTEM TEST
CONTINGENCY
LEAK TEST
INSTALL PYRO
FUEL
MATE TO SHROUD
INTEGRATED
LEAK CHECK
LEAK TEST
DEMATE FROM SHROUD
UNLOAD FUEL
NO-GO
ISOLATE MALFUNCTION
REMOVE FAILED UNIT
1 TO 5 DAYS
FUEL
SUBSYSTEM TEST
REPLACE FAILED UNIT
MOVE MODULE
REPLACE MODULE
SUBSYSTEM TEST
DEMATE FROM SHROUD
UNLOAD FUEL
REMOVE FAILED UNIT
1 TO 5 DAYS
ISOLATE MALFUNCTION
FUEL
SUBSYSTEM TEST
REPLACE FAILED UNIT
FIT CHECK
STORE
NOSE FAIRING
R&I
MECHANICAL MATE SHROUD-2
MECHANICAL MATE SHROUD-1
MATE AND CONNECT PV-1 AND PV-2 SIMULATORS
MATE FAIRIN
SV ELECTRICAL MATE
SWITCH AND ELECTRICAL FUNCTION TEST
PV-LV SIMULATOR INTEG TEST
ELECTRICAL MECHANICAL SYSTEM CHECKS
VA COMPO READI TEST
G&C CHECKS
PROPELLANT DISPERSION TESTS
POWER TRANSFER TEST
S-II – S-IVB NET SUBSYSTEM TEST
VAB HIGH BAY
ALIGN & ERECT PREP
ERECT
TCS CHECKS
POWER ON & DDAS CHECKS
INSTALL G&C
INSTRUMENT UNIT
R&I
RF AND TM CHECKS
ELECTRICAL, INSTRUMENTATION, AND MECHANICAL CHECKS
VAB LOW BAY
VAB HIGH BAY
ERECT
POWER ON AND DDAS CHECKS
S-IVB STAGE
R&I
RF AND TM CHECKS
ELECTRICAL, INSTRUMENTATION, AND MECHANICAL CHECKS
VAB HIGH BAY
ERECT PREP
ERECT
ERECT AND MATE TO INTERSTAGE
PRE-POWER CHECKS
POWER ON AND DDAS CHECKS
S-II STAGE
R&I
INSULATION LEAK CHECKS AND PROPELLANT CHECKS
RF AND TM CHECKS
ELECTRICAL, INSTRUMENTATION, AND MECHANICAL CHECKS
VAB LOW BAY
VAB HIGH BAY
ERECT PREP
ERECT
PRE-POWER CHECK
POWER ON AND DDAS CHECK
S-IC STAGE
R&I
INSTALL FIN AND FAIRINGS
RF AND TM CHECKS
ELECTRICAL, INSTRUMENTATION, AND MECHANICAL CHECKS
VAB LOW BAY
VAB HIGH BAY

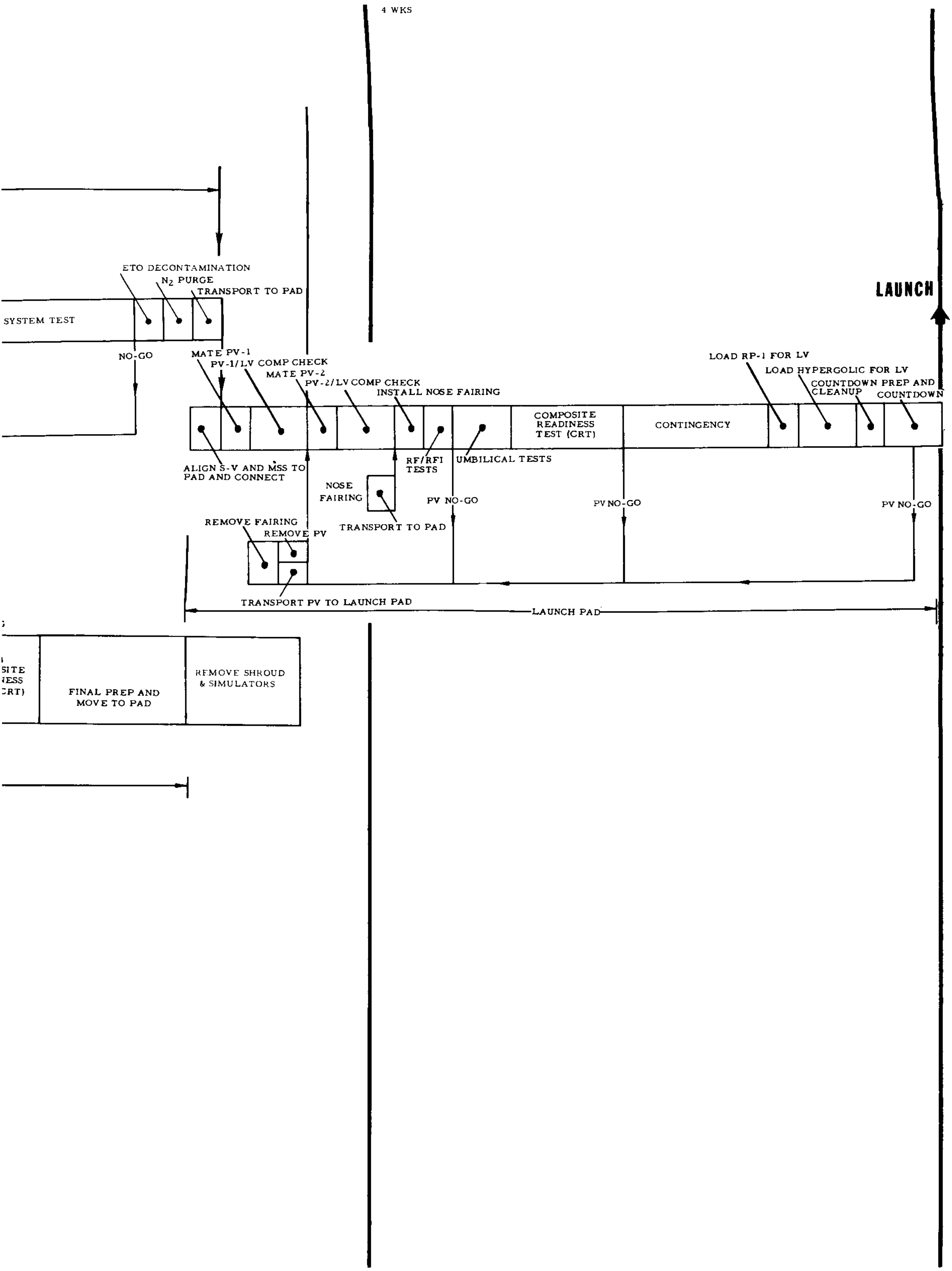


Figure 7. System Flow at Launch Site (Continued)

Two planetary vehicle-shroud assemblies are transported to the launch pad and mated to the launch vehicle. Mechanical and electrical connections will be made and electrical continuity test conducted. After individual planetary vehicle system checkouts, the two vehicles are operated together to check for interference. The nose fairing is then mated to the forward shroud section interface structure for mechanical alignment checks of the total assembly. Discrete signals required between the launch vehicle and planetary vehicle will be exercised and system performance evaluated. After successful completion of the compatibility test a countdown readiness test will be conducted. After the Voyager mission readiness condition is obtained from the Voyager mission director, the space vehicle test conductor initiates the final countdown sequence.

10.2 SALIENT FEATURES AND ALTERNATIVES

The Voyager planetary quarantine requirement has a strong impact on launch operations. The heat sterilization cycle for the capsules and the surface decontamination and encapsulation of the planetary vehicles are complex innovations with many ramifications in facilities, support equipment, procedures, and personnel training. The requirement that class Fed 209-100 clean rooms are utilized for capsule operations and class Fed 209-100,000 clean rooms are utilized for spacecraft and planetary vehicle prelaunch operations also represents a complex innovation. In addition, all transportation and handling of capsules, and spacecraft outside of the clean rooms will be in environmentally controlled protective covers, to prevent contamination of the units.

An important feature of Voyager launch operations is the provisioning of a flight-ready encapsulated planetary vehicle as a spare in case a primary article develops unexpected difficulties during any phase of final space vehicle checkout, countdown, and launch operations. The interchanging of the complete planetary vehicle-shroud assembly module will expedite overall checkout operations and will aid in achieving the required 20-day launch window. An additional spare capsule will be processed to a flight-ready condition for recycling ESA operations on the unit returned from the pad, to create a new flight-ready spare. Further study is required on the feasibility of such an arrangement to justify the expense of a fourth flight capsule.

Another important feature is the policy allowing replacement of only assembly modules at the launch site and not components. This will aid in reducing the total maintenance time for faulty components at the launch site. It will also reduce the complexity of the checkout equipment by the elimination of fault isolation at the component level. Thus fault isolation to the component level will be relegated to specialized checkout equipment at the factory, where the failed module will be sent for final repair.

As noted in the launch site operations flow, all operations on any given segment of the vehicle such as the capsule or spacecraft are staggered between each of the separate end item capsules or spacecraft. This enables one checkout set to be utilized, thus cutting overall checkout equipment requirements to a minimum. Contingencies are allowed for in the staggered operations and many of the checkout features can be accomplished on a noninterfering basis with each succeeding capsule or spacecraft. Total checkout set requirements at the launch site equals two for the capsule and two for the spacecraft, with the capsule and spacecraft checkout site combined in the explosive safe area for planetary vehicle operations. The spare module concept for replacement of checkout equipment malfunctions will be applied in the same manner applicable to flight hardware.

Fueling operations which are conducted in the explosive safe facility will enable fueling of the spacecraft prior to shroud encapsulation and ETO decontamination. This eliminates fuel line umbilical connections through the shroud to the spacecraft, which then would require separation of umbilicals during shroud-spacecraft separation operations after injection into the Mars transfer trajectory.

The general policy for Voyager launch operations for the reference approach is to utilize key members of the test team which performed the operations on a particular flight article during factory checkout and acceptance to perform operations on this article at the launch site. This will enable the launch site team to be familiar with the vehicle and prelaunch operations and reduce the time to perform preflight checkout operations.

Launch vehicle to planetary interface checks are associated directly with shroud encapsulation rather than with mating of the shroud to the Saturn V booster. Hence the planetary vehicles are not required in the VAB during shroud-booster checks, but can be replaced by suitable simulators.

In contrast to the reference on-pad mate, mating the two planetary vehicle shroud assemblies is possible in the VAB, similar to the operations now utilized for the Apollo program. However, there are a number of potential problems in mating the planetary vehicle-shroud assemblies in the VAB, entailing safety features and required facility modifications. Several safety restrictions now exist in the VAB relating to pyrotechnics, fueling, etc. If the spacecraft is fueled prior to mate of the planetary vehicle-shroud assembly in the VAB the safety problems must be investigated as well as the effect of the weight of the fueled planetary vehicle-shroud assemblies on the launch vehicle and associated facilities and equipment in the VAB. Mating of the planetary vehicle-launch vehicle in the VAB eliminates final system checkouts and mating of the planetary vehicle-shroud assemblies with the Saturn V for the first time when they arrive on the pad. Hence the total on-pad time is reduced for this concept. A number of detailed facility and equipment modifications will require investigation, such as the modifications required to the VAB vertical assembly bay workstand crane hook heights, crane weight capacities, etc. Also an investigation is required to determine the dynamic effects upon the mobile crawler transporter if a fully loaded planetary vehicle-shroud assembly is installed and moved with the launch vehicle to the pad.

Tradeoff studies should be conducted to determine alternative modes of operation for fueling the spacecraft. The reference approach calls for spacecraft fueling in the explosive-safe area prior to encapsulation in the shroud. A number of alternates are available. Impact upon the spacecraft and shroud design would result if fueling follows planetary vehicle-shroud encapsulation. This will involve a fuel line umbilical from the shroud to the spacecraft which will require either in-flight or remote disconnection.

11. MISSION OPERATIONS

The Voyager mission operations system management office is responsible to the Voyager mission director for mission operations facilities, equipment, software, and associated personnel to support the Voyager mission. This responsibility covers in particular all mission-related activities from earth parking orbit injection through the end of Mars operations. It also covers MOS prelaunch activities in support of the LOS and planetary vehicle monitoring and evaluation for the ascent flight phase. The MOS manager therefore has an overall responsibility for the developmental and operational activities associated with mission operations, including activities of supporting organizations. This includes all activities associated with Voyager MOS analysis, system design, development, and procurement. He will exercise control of all elements of mission operations and will be responsible for coordinating the associated elements.

11.1 GENERAL APPROACH

Operations in support of the Voyager missions will begin in 1973 and extend beyond 1984 for the three-generation program, a period approximately equal to a full generation in the evolution of ground operational complexes. Thus the planning for Voyager flight operations must begin immediately and be directed toward an approach which will embody operational methodologies, equipment, and software that are sufficiently advanced to survive the next generation of technological advancement and hopefully to establish the pattern for flight operations during that era.

Much has been done over the past decade in organizing the world-wide tracking networks for simultaneous support of the maximum number of space systems, and steps have been taken toward standardization of equipment, facilities, communications, and operational procedures. In recent years progress has been made in formalizing the "central point of control" concept in spaceflight operations. Tracking networks previously dedicated to research and development have matured in their new roles of multiple project support of operational spaceflight programs. In expanding to this new role they have developed the configuration management, standardization of procedures, and interface control practices required for effective implementation of simultaneous multiple mission support.

The Voyager mission operations planning should endeavor to further the progress which has been made along these lines. Because of the increasing number of space projects which must be supported by the tracking networks, spacecraft system design should consider the problems associated with multiple project support in implementing the flight systems. To the maximum practical extent the flight and ground systems should be designed for periodic as opposed to continuous coverage by the tracking networks. This concept can be enhanced by:

- Utilizing high communication data rates
- Providing storage capacity in spacecraft systems to preserve data during periods of limited ground coverage
- Transmission of commands in blocks to update space command programmers at periodic intervals and minimize the number of acquisitions for individual command transmissions
- Bandwidth conservation through the use of error correcting codes so far as is consistent with increased equipment complexity
- Design of communications equipment to minimize the time required for acquisition of the space-to-ground and ground-to-space links

From the standpoint of ground operations, Voyager is the ideal project to maximize the use of automation in the interest of operational efficiency and cost effectiveness. Many of the constraints which apply to manned spaceflight operations will not apply to Voyager so far as mechanizing operational decisions are concerned. Further, because of the long operational life of the Voyager system and its complexity, the maximum yield in cost effectiveness from computer control in elimination of personnel functions can be realized. And finally the possibilities for interrelation of activities between the various Voyager vehicles after arrival at Mars can be exploited through the use of simultaneous monitoring and correlating data by ground computers.

Voyager system design should adhere to the principles of maximum information yield in the shortest practical time with minimum data flow and storage. The following measures should be considered in support of this concept.

1) Self adaptive telemetry systems and data compression techniques should be utilized wherever possible to minimize transmission of redundant and unnecessary data.

2) The ground data system design should provide for near real-time processing and display of all operational data (both engineering and scientific) which can contribute to optimizing the scientific mission, improving the performance of the planetary vehicles, prevent degradation to some element of the system.

3) The necessary data quality assessment capability should be designed into various elements of the system faults from anomalies in spaceflight hardware.

4) The necessity for collection of large quantities of raw archives data should be avoided by:

    - Use of digital recording at the Deep Space Stations and development of a data processing system capable of fully processing all data for distribution to users on a daily basis as the data is received, thus eliminating handling of analog instrumentation tapes except in cases of temporary malfunction

    - Use of on-line engineering analysis teams and science analysis teams with real-time computer support to sort, sift, collate, and analyze the data and to generate the performance analysis reports. This will help prevent an accumulation of large backlogs of data and will provide the expeditious reporting necessary for feedback into mission planning and system design for the subsequent mission on a two-year launch cycle.

The most demanding requirements for the mission operations system and the tracking and data acquisition system stem from supporting the long stay surface laboratory. Therefore, the initial design should provide the capability for full support of these ultimate requirements except in those cases where extension capability can be designed into the system to provide for later growth with negligible effect on the system in existence. The basic design goal is to avoid large, costly changes to the operational systems during the life of the project. Even though this approach may lead to excess capability for the more simplified early missions, as long as this excess capability is not activated prematurely the residual costs associated with maintenance of the excess capability early in the program should be small compared to the cost associated with significant changes to the operational systems between Voyager generations. Activation of the full mission operations capability will be phased over the life of the program in accordance with the success achieved in scientific discoveries during each mission.

Readiness to support a Voyager flight will be assured by a sequence of three implementation phases. The first will consist of establishing basic policies of Voyager mission operations by specifying the broad guidelines for MOS preflight planning and design, flight operations support, documentation, scheduling, computer program design, development, and maintenance control activities. Guidelines for the procurement of mission-dependent equipment are developed. Preliminary software configuration control practices are delineated, internal and external MOS interface control procedures are defined, and detailed requirements are imposed upon various MOS elements to assure system operational readiness at the required time.

The second MOS phase consists of development of operations procedures, the preparation of test instructions and data packages, development and integration of computer programs, and the fabrication, delivery, and system integration of mission-dependent equipment.

The third phase corresponds to a comprehensive system test and training program for all personnel and mission-dependent equipment. The achievement of operational readiness status will be consistent with all mission schedules.

11.2 IMPLEMENTATION ALTERNATIVES

The basic tradeoff between exploration capability and system complexity has strong implications on mission operations. One particular aspect relates to the high data rate and the concomitant data handling requirements. In this regard, the high data rate can also be utilized to reduce periods of coverage by the ground system, in exchange for less total transmitted data.

During certain mission phases, DSIF station complexes can be used to divide the tracking, command, and telemetry data handling functions between two Deep Space Stations rather than having a single station service all functions. To provide this alternate mode of operation will require additional complexity but can provide for a more balanced operational loading when both stations of a given complex are available to track Voyager. However, the capability must exist for a single station at each complex to service all data handling requirements from both vehicles during periods of extended maintenance or multiple project conflict causing one of the stations in a two-station complex to become unavailable. Furthermore in the event of spacecraft malfunction which reduces effective radiated power or during periods of extended range operations the 210-foot antenna station at each complex may be the only station capable of servicing the Voyager vehicles.

A significant feature of the reference approach is the use of alternate modes of operation for the major data handling function associated with tracking, telemetry, and command data. During periods of high activity such as maneuvers and mapping activity the direct coupled computer system at the SFOF is operated on-line for near real-time processing of data and commands. During periods of low activity such as cruise mode operation or in the event of unavailability of the direct coupled computer system at the SFOF, the Deep Space Station computer will have an alternate program which will allow minimal processing of data and generation of commands under control of the SFOD at SFOF but independent of the SFOF equipment and high speed communication lines. A tertiary mode of operation will be designed into the system which allows intermediate level processing of telemetry data through use of the telemetry processing station at SFOF while commanding through the station computer. This mode permits a higher level of data processing in real-time than can be achieved via the station computer and at the same time relieves the direct coupled computer complex, providing a means of accomplishing all routine mission functions during noncritical phases.

Organization of the functional analysis and command teams at the SFOF may employ slight alternatives from the organization of the reference approach. The reference organization utilizes more centralization for command activities than presently employed at the SFOF through the use of a command coordinator at the staff level to the SFOD, rather than having this function reside in the various functional support areas. A further step toward overall centralization of the supporting analysis and command groups is to incorporate the space science analysis and command group into the planetary vehicle performance and command group. The functions of science analysis and command recommendations for each of the science payloads (spacecraft, capsule, and surface laboratory) can thus perform their activities in close coordination with engineering analysis functions.

12. TRACKING AND DATA ACQUISITION SYSTEM

12.1 SCOPE AND FUNCTIONS

The tracking and data acquisition system management office, under the direction of the tracking and data acquisition system manager, is responsible to the Voyager mission director for acquiring Voyager tracking and telemetry data and transmitting commands. The TDAS will provide the following functions in support of the Voyager mission:

- Track the space vehicles and provide metric tracking data
- Receive, record, and relay telemetry data from the space vehicles
- Transmit commands from the operations teams to the space vehicles
- Provide station performance parameters which are required for analysis and evaluation of vehicle performance
- Provide and maintain a library of master data records developed during each flight
- Provide acquisition data required by tracking and data acquisition stations

The Voyager project will make use of selected stations and equipment of the AFETR, the NASA networks managed by the Goddard Space Flight Center, and the DSN. Since the range and the NASA networks are undergoing continual development, Voyager will undoubtedly use the new capabilities to meet requirements as stated in the program and support instrumentation requirements documents.

For Voyager the AFETR will track the launch vehicles, receive telemetry from the launch vehicle, each spacecraft and each capsule, and provide data handling support during the near-earth Voyager operations. Instrumented aircraft, ships, and range stations will track the vehicle from launch to provide metric and telemetry data. These aircraft-, land-, and ship-based systems will be linked with the KSC and the SFOF during near-earth operations.

The MSFN, either through its own stations or those of other networks managed by the GSFC, will provide metric and telemetry coverage to supplement AFETR coverage during the phase from liftoff to planetary vehicle injection. Selected MSFN stations may be used to provide coverage for gaps which exist either in the AFETR or the DSN in meeting project requirements.

12.2 SYSTEM OPERATIONS

TDAS operations may be grouped into flight preparation, flight support, and postflight activities. During flight preparation all necessary planning, design, development, procurement, integration, and testing are performed to assure system operational readiness. Flight support includes tracking, data acquisition, data handling, and participation in mission operations. Postflight TDAS activities encompass system performance evaluation and flight navigation data processing.

12.2.1 Flight Preparation

Normally, requirements for support by network resources are documented in a project support requirements document. The final welding of the major elements of the TDAS into a functional unit will occur by means of a comprehensive training and test program. A master program comprising three basic categories of tests will be implemented to train mission personnel and to verify that the equipment and operational capabilities of the TDAS are adequate for Voyager.

Internal facility tests will establish that support facilities function properly. Functional compatibility tests will ensure that the facilities are functionally compatible with each Voyager vehicle and with each other. Finally, operational readiness tests will ensure that all elements of the TDAS operate together by demonstrating readiness to support space operations.

The TDAS manager will insure that all AFETR, DSN, and MSFN elements are properly configured to support the Voyager project. The TDAS management must consider a large number of project activities of varying priorities. When necessary, alternative plans are recommended to the project manager. All of the work at all of the stations and at the SFOF is scheduled by the TDAS scheduling office.

12.2.2 Flight Support

During the in-flight phase the TDAS provides in-flight navigational information to the project. After planetary vehicle injection the essential functional relationships are as follows:

1) The Deep Space Stations take precision doppler measurements by transmitting a signal to the space vehicle which is returned by means of a turn-around transponder. Pointing information and range data may also be derived.

2) Measurements from the Deep Space Stations are transmitted to the SFOF.

3) The measurements are analyzed, edited, and processed to improve previous trajectory estimates.

4) The monitor area provides alarms and recording equipment to monitor the status of the stations, SFOF, and data stream.

5) Antenna pointing data is generated for the Deep Space Stations for succeeding acquisitions of the spacecraft.

6) The improved orbit estimates are given to the trajectory group. This group then analyzes the trajectory for the project.

7) During the flight maneuver and orientation, analyses are performed to determine how best to achieve mission objectives.

8) The inputs from maneuvers are sent to the SFOF, where the commands are then formulated. Inputs from the SFOF on space vehicle maneuvers and space vehicle perturbations are also fed into the data analysis and orbit process to account for apparent trajectory anomalies and to predict correlations.

12.2.3 Postflight Activities

After flight operations, in-flight TDAS performance is re-evaluated, data is validated, astrodynamic constants determined, and recommendations for improvement of TDAS performance in support of future Voyager missions are submitted to the Voyager project manager.

Data is edited by inspecting station records, space performance and command group reports, the interim monitor program, and operations records, in addition to the orbit program plots and residuals. The accuracy of the orbit program often makes it the final arbitrator as to whether data are good or bad. Thus, the data editing and the orbit determination process are tied together in an iterative process. This effort, extending anywhere from 1 month to 1 year after the flight, is to:

- Provide the project with a "best estimate" of the trajectory
- Provide better estimates of physical constants and station locations
- Provide data analysis for inherent accuracy and applicability

13. MISSION ANALYSIS AND ENGINEERING

Project-level mission analysis and system engineering are essential to meet the operational challenges of the Voyager missions. Orbits, trajectories, and mission sequences need to be studied from a viewpoint encompassing all Voyager systems to the end of assuring that project goals, particularly the scientific objectives, are attained in the correct and predetermined manner.

To insure uniformity of approach and to provide the necessary system engineering support to the project manager, an office of mission analysis and engineering at the project level appears to be essential. In particular this office encompasses the following:

- Identification of LOS, MOS, and TDAS operational constraints
- Planning and design of mission reference trajectories
- Definition of targeting specifications for mission maneuvers
- Development of guidance, targeting, and navigation software for mission maneuvers
- Evaluation of mission feasibility
- Determination of the sensitivity of the trajectory to system errors and mission parameters
- Preparation of launch support information for launch approval and the generation of operational range safety aids
- Generation, maintenance, and dissemination of official mission-related vehicle and system data
- Preparation of operational flight data. The mission design and analysis effort includes specifying interface control documentation, resolving system interface conflicts, and managing intersystem integration engineering activities in relation to flight operations.

13.1 MISSION OBJECTIVES

It is necessary to define the Voyager mission and flight objectives so that a uniform set of goals can be established for all phases and project interfaces. Significant performance requirements must be specified and a guide established for the design of all operations.

The Voyager objectives require an orderly program of continually improving knowledge in science and technology. The aspects of such a program include:

- Scientific and engineering observations and experiments directed towards extending the capability of Voyager to operate near Mars and on the Martian surface, and efficiently developing this capability throughout the duration of the Voyager project

- Scientific and engineering observations and experiments directed toward extending the capabilities of the scientific instruments to operate near Mars and on the Martian surface, more specific definition of future experiments concerning exobiology and planetology, and the efficient development of these capabilities throughout the duration of the Voyager project

- Scientific observations and experiments concerning possible biology and biochemistry of Mars

- Scientific observations and experiments concerning the physics and chemistry of the Martian surface and atmosphere directed toward obtaining information essential to the advancement of planetology

A major function is to establish the Voyager operational requirements and to insure that the necessary resources are committed to support the Voyager missions. Working through the systems management offices, this organization insures that all interfaces are properly effected and that the planning and scheduling of operational personnel, hardware, software, and facilities is as required. To carry out such activities a flight operations working group is to be established at the project level under the chairmanship of the MA and E manager. The group should consist of members from each Voyager SMO, each NASA and DOD management or interfacing agency, and members from all major contractors. In particular, science payload considerations should be represented by a science coordinator from the spacecraft, capsule, surface laboratory, and mobile unit contractors to coordinate the matters related to science experiments for their respective systems.

13.2 MISSION FEASIBILITY EVALUATION

The feasibility of each Voyager mission needs to be evaluated by defining the individual vehicle performance capabilities and projected maneuver dispersions. Each vehicle is analyzed as to its ability to perform the requisite maneuvers, and each performance capability is documented separately, including an associated dispersion analysis. One document will be issued to summarize the effects of all system errors upon mission success.

13.3 TRAJECTORY PLANNING AND DESIGN

Trajectory planning and design will provide planning and design information for launch, mission, and tracking operations; specify trajectory design requirements and guidelines; official mission and trajectory data in a coordinated format; and design characteristics of the trajectories and powered flight maneuvers.

Criteria for the selection of Mars landing sites are presented and justified. Trajectory constraints, shaping criteria, and design guidelines are presented for each mission phase from prelaunch to postlanding operations. Design targeting specifications are issued for operational trajectory development, prelaunch operational targeting, and preflight computation efforts.

The trajectory analyses define the launch-to-mission-completion trajectory characteristics; establish requirements for all vehicle maneuvers; present pertinent mission and vehicle information; demonstrate the extent to which the trajectories are within allowable design limits; and provide planning information for launch operations and tracking station support.

14. FUNCTIONAL MANAGEMENT

14.1 PLANETARY QUARANTINE

As discussed in the JPL document, "Planetary Quarantine Plan, Voyager Project," revised January 1, 1967, a basic policy in the NASA program for exploring Mars is to quarantine the planet from terrestrial life forms until adequate time has passed for exobiological studies. The quantified constraints that this objective places on the Voyager project are as specified in the quarantine plan. To meet these objectives two types of activities need to be undertaken in the Voyager project: studies and implementation of techniques for prelaunch sterilization and contamination avoidance and studies and implementation of mission operations to avoid the possibility of impact of unsterile particles on Mars.

Although under nominal circumstances during the Voyager mission only the capsule will make physical contact with Mars, the studies that precede the formulation of the precise mechanisms for quarantining the planet need to incorporate the spacecraft as well. Exhaust from the spacecraft engine during midcourse and orbit-injection firing and from attitude-control jets during interplanetary cruise and orbit operations can conceivably reach Mars. Micrometeoroids striking the spacecraft can eject material from the surface which can enter trajectories that impact Mars. In short, no portion of the planetary vehicle or its operations can be overlooked in the studies of the means to achieve quarantine.

Following an initial set of studies and experiments, the Voyager monitoring, control, and capsule sterilization procedures will be detailed in a formal sterilization plan compatible with the planetary quarantine plan. When it is approved, the sterilization plan will be the controlling document for sterilization procedures. The plan will cover:

- Mathematical models for predicting the probability of contamination from all sources
- Sterilization facilities and operating procedures and techniques

- Means for preassembly sterilization, assembly in a quarantine assembly facility, heat sterilization following assembly, and maintenance of the integrity of the sealed capsule canister

14.2 DATA MANAGEMENT

The Voyager data management program will serve to define and implement all data needed for the project, to see that required data is available when needed and is accurate and adequate, but that no data is handled which is not essential. The program will be based on the NASA data management system established for the Apollo program and described in NPC 500-6.

Primarily responsible for the Voyager data management program will be the data manager on the staff of the project manager for administration and control. The responsibility entails:

- The analysis of project data requirements and the specification of content, form, distribution, and related factors
- The development, implementation, and monitoring of systems and procedures for the identification, definition, generation, preparation, production, and reproduction of project data
- The generation, preparation, production, reproduction, and distribution of selected project data
- The review of data to be released from or approved by project elements to ensure that all review steps have occurred and that the data are consistent with the overall project data program
- The development, implementation, and monitoring of systems and procedures for the acquisition, receipt, recording, routing, indexing, storage, retrieval, and transmittal of data

14.3 CONFIGURATION MANAGEMENT

A formal system of configuration management will be used by the Voyager project, based on NPC 500-1, to assure that equipment is accurately defined at all times and to promote an orderly evaluation of changes in equipment throughout the program. The system will entail administrative control of the technical requirements documents and changes thereto, in coordination with the data management system. Primary responsibility for configuration management will be given to the configuration management office in the staff of the manager for administration and control.

Following the Voyager Configuration Management Manual, five types of activities will be provided in the configuration management program:

1) Uniform specification program
2) Configuration baseline management
3) Configuration identification
4) Configuration control
5) Configuration accounting and reporting

In addition, the program will provide for complete computerized traceability of drawings, parts lists, and all other equipment-related documents and the interface control specifications as they affect the configuration. For all project elements and contractors the program will provide a single-point release of configuration data and approved changes, with change approval authority clearly defined.

The foundation of the configuration management system is the concept of baseline management, achieved by establishing and managing formal baselines or points of departure at major commitment points in the project schedule. Baselines and formal reviews on the Voyager project will serve as configuration management reference points to control the evolution of design documentation and the hardware.

14.4 PROJECT CONTROL AND REPORTING

The Voyager project scheduling and resources management system will provide schedule information, contractors' resource data, and time-cost data for management control purposes. Project and system level status will be displayed in the Project Control Room. All reporting of resource data will be against the work breakdown structure; PERT networks and fragnets will correspond to specific items in the work breakdown structure; and all reporting will be against categories of the work breakdown structure.

14.5 INTEGRATED TEST PLANNING

A close link must be maintained between the engineering design and test requirements definition, test planning, test implementation, and test evaluation. The various categories and levels of test must be properly related to supplement each other.

Accordingly, an integrated test plan is prepared for each system covering all testing from parts and materials to top-level system and intersystem tests. The applicable system integrated test plan will be prepared by each system implementation organization, subject to approval and control by the cognizant system management office. An intersystems test requirements document is to be prepared by the project office to cover all tests with participation by more than one system. The detailed role of each system in such intersystem tests will be contained in the applicable system integrated test plans.

The plan forms an agreement between the implementing organization and the cognizant SMO relative to overall testing plans and the reporting against those plans. The plan assures technical adequacy of testing, and serves as a means of assessing test value. The test plan is a major part of the SMO technical monitoring effort. Initially, it is a review of the test implementation so that adequate allocation of resources for testing can be assured prior to the onset of design activity.

14.6 PROJECT RELIABILITY

The Voyager project reliability assurance manager will formulate the project reliability program plan to specify the adaptation of NASA NPC 250-1 for Voyager. The plan will define the basic requirements that all individual Voyager system reliability program plans need to meet. These plans will then be prepared by the contractor or agency responsible for each system. The basic requirements imposed on the system plans will include:

- Standardized reliability procedures throughout the project
- The maximum possible use of existing government standards, practices, and procedures
- Departure from NPC 250-1 only after justification and approval, with specific identification of the departure in the system plan
- Definition of responsibilities for reliability for all organizational elements
- Application of MIL-STD-217 for standards applied to reliability prediction
- Compatibility of system reliability analyses with mission analyses
- Justification for selection of parts without a history of successful space application

The reliability program will be subdivided into at least eight elements for purposes of monitoring and control:

- Reliability program management
- Design support and analysis
- Design review and control
- Parts control
- Materials and processes control
- Supplier control
- Failure reporting and correction
- Reliability testing

In all of these areas the reliability program plan will specify objectives and milestones and prescribe the documentation and monitoring requirements.

14.7 QUALITY ASSURANCE

A quality assurance plan for the Voyager project will be established by the project quality assurance manager, based on the provisions of

NPC 200-2, to prevent defects in manufactured articles and assure conformance to design and performance criteria. The plan will cover:

- Design and development control
- Supplier control
- Inspection and certification
- Process and fabrication controls
- Sampling
- Workmanship standards
- Nonconforming materials control
- Acceptance test verification
- Handling, shipping, and storing procedures

15. PROJECT COSTS

Cost estimates for the entire Voyager project as defined in this study have been generated. Gross scaling costing techniques have been utilized rather than detailed pricing analysis, since such analysis was beyond the resources of the study and not justified for the general level of definition being developed. The results are provided in the supplement to the report.

The initial step in developing the cost estimates was to use the Space Planners Guide wherever applicable. When using the cost curves contained in the Space Planners Guide, the necessary parameters were obtained from the "Voyager Support Study, Advanced Mission Definition Final Report, Volume I, Preferred Approach." In most cases, these parameters consisted of subsystem weights. Wherever applicable, the results of prior cost studies generated either by TRW or other contractors were used. Examples of costs obtained in this manner were the mobile unit (General Motors), the Voyager shroud system (McDonnell-Douglas), and the propulsion system (TRW Systems). A report written by Aeronutronics contained costs on a landed science payload. Since these costs were not in a directly usable form, they were only used as a check on the Space Planners Guide methods. The costs are given in 1967 dollars in keeping with the adjustment recommended by the Space Planners Guide.

The cost of the Saturn V launch vehicle was obtained from "NASA Authorization for Fiscal Year 1967, Hearings Before the Committee on Aeronautical and Space Sciences, U.S. Senate." This document was also used for the cost data on the operational systems such as the tracking and data acquisition system.